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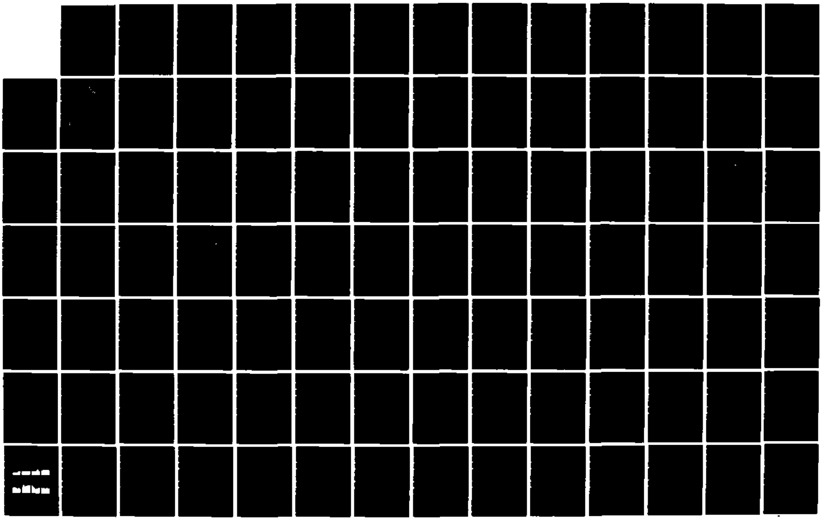

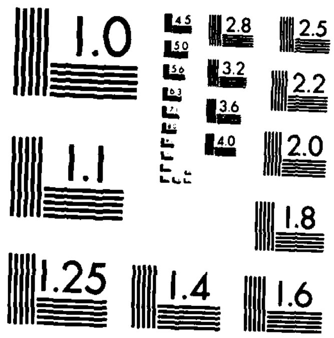

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WARTIME CONUS CASUALTY DISTRIBUTION

SYSTEM USING DEDICATED CRAF AIRLIFT

THESIS

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AFIT/GST/OS/85M-1

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Abstract

The objective of this ~~research~~ was to test the feasibility of using Civil Reserve Air Fleet (CRAF) aircraft and C-9 aircraft to deliver wartime casualties to CONUS hospitals. The method of distributing the patients was by a HUB-and-spoke-type system. The distribution system was analyzed under a scenario which represented an intense European conventional war. Casualty inputs into the distribution system were estimated to be approximately 1000 patients per day. The casualty distribution system was modeled using SLAM simulation and FORTRAN computer code.

Factors of interest to the Military Airlift Command (MAC) were varied to determine the number of CRAF necessary and the capacity of these CRAF aircraft. In addition, trend analysis of C-9 requirements was accomplished. Results of the simulation analysis indicate that the system developed appears feasible. However, the number of C-9 aircraft necessary to adequately operate the system is in excess of current Air Force CONUS capabilities.

The model has additional flexibility. By changing input variables and distribution parameters to fit new environments, the analyst can model different scenarios and types of aircraft. Analysis of hospital beds and their impact on the patient distribution system can also be accomplished.

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WARTIME CONUS CASUALTY DISTRIBUTION SYSTEM
USING DEDICATED CRAF AIRLIFT

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Operations Research

Joseph P. Alfano, B.S.
Captain, USAF

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Captain, USAF

March 1985

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Preface

The purpose of this study was to provide insight into the development and feasibility of a war-time CONUS casualty distribution system using dedicated Civil Reserve Air Fleet (CRAF) airlift in a multiple HUB-and-spoke-type operation. This research was undertaken to seek out alternative methods of distributing casualties to CONUS hospitals in the event that the present Military Airlift Command aeromedical evacuation plans can not adequately support current casualty estimates for a European war.

There are many people who contributed to this research effort. We are deeply indebted to Major James R. Coakley, our thesis advisor, who unselfishly gave of his time and knowledge in guiding us throughout this study. We are also grateful to LtCol Dennis McLain and the people at the Military Airlift Command's Operations Research Division (XPSR), Scott AFB, Illinois who first presented this topic to us and TSgt Linnes Chester of the Medical Readiness Division, Fort Sam Houston, Texas. We especially appreciate the time they took from their busy schedules to provide their insights and resources so we could better understand and analyze a problem of real-world significance. Finally, a special thanks is extended to Lauren O'Neill and our families whose loving support and encouragement made this thesis possible.

Table of Contents

List of Tables

List of Figures

Abstract

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WARTIME CONUS CASUALTY DISTRIBUTION SYSTEM USING DEDICATED CRAF AIRLIFT

I. CONCEPTUALIZATION

Introduction

Casualties are an unfortunate consequence of war. The manner in which a nation handles its casualties is important in terms of regaining highly trained soldiers for combat; especially when manpower is critical. Moreover, the perception soldiers have of their chances for evacuation and follow-on medical treatment in the event of injury will affect the morale of a nation's combatants. However, no matter how many casualties result, a nation must first use its resources to achieve the higher goals for which the war was entered. The transportation of casualties becomes of secondary importance to the primary mission of waging war.

None the less, because of the rapidly increasing ability of adversary nations to wage war, the number of casualties expected from an intense European conflict is enormous. The problem of transporting casualties back to the CONUS and distributing them to medical facilities is becoming increasing complex in light of these large casualty estimates and this nation's limited airlift resources. This research will address current studies on this issue, highlight the current patient distribution plan, and focus on the presentation and analysis of an alternative CONUS

patient distribution system. This alternative patient distribution system will be based on a Military Airlift Command (MAC) proposal to use dedicated civil reserve air fleet (CRAF) aircraft in an aeromedical evacuation role.

Background

A basic requirement for the Air Force Medical Service during wartime is to maintain and restore to health (war-related) casualties to ensure maximum combat effectiveness of our forces. To be able to maintain this wartime readiness, the medical services and related aeromedical evacuation resources (Military Airlift Command) must maintain certain peacetime levels. However, because there has been a significant increase in the enemy's capability to wage war, the anticipated number of U. S. casualties has likewise increased significantly. The Medical Readiness Division of the Office of the Surgeon General anticipates current European theater medical capability would be rapidly overwhelmed. To relieve the burden on European hospitals, the U. S. Department of Defense plans to evacuate casualties to the CONUS under the following policy:

> "During the first 30 days of a conflict, if a wounded soldier cannot be returned to duty within 15 days, then he will be evacuated to a medical facility in the United States." (19:2)

However, MAC anticipates there may well be a severe shortfall in the required number of aircraft for the CONUS

Research Objectives

Objectives of this research effort are twofold:

1. Simulate the distribution of casualties, to CONUS hospitals, using the civil reserve air fleet aircraft (CRAF) patient distribution system under a realistic wartime scenario to evaluate the feasibility of such a system.

2. Conduct sensitivity analysis to determine maximum capacity, possible improvements in the patient distribution system and gain insights into aircraft requirements.

Summary

The present casualty distribution system the Military Airlift Command plans to use during a European war uses C-141 aircraft to transport the patients to the CONUS. The patients will then be transported to locations in the CONUS comsensurate with the C-141s primary wartime mission (the resupply of the European Theater). C-9 aircraft are then required to rondezvous at these locations in order to make plane-to-plane transfers of the patients and then on to their hospitals.

However, due to the huge number of casualties anticipated from such a conflict, there is a question as to the feasibility and efficiency of the present system. The Joint Chiefs of Staff directed a study which is being done by the Military Airlift Command's Operations Research Division in conjuntion with Southern Methodist University to answer these questions. An alternative system proposed by MAC is to use CRAF aircraft dedicated solely to the

condition will not be jeopardized. The current system of transporting patients, using C-141 aircraft on resupply missions will work. The question of how effectively it will work is being studied by the Operations Research Division at Headquarters MAC. We feel that the average time a patient spends in any air evacuation system is an important factor when comparing alternative systems. Therefore, it was used as the primary measure of effectiveness. A secondary measure of effectiveness considered was the maximum time patients spend in the system.

Problem Statement

The current capabilities of airlifting wartime casualties within the United States is a topic of discussion within the JCS, Congress, the Military Airlift Command and the Military Readiness Division. Consequently, there is a need to model a casualty distribution system under a wartime scenario to assess the system and its capabilities. There is also a lack of data in the current tri-service computer model for aeromedical airlift transport of casualties. Therefore, a model of the airlift portion of the patient distribution system would be helpful in improving the data base for the tri-service computer model.

and ends when the patients are offloaded at their destination hospital. The influx of casualties into the CONUS will be those patients who cannot be returned to active duty within 15 days.

The means of distributing the patients will be a hub system. The concept of such a system is similar to the Federal Express method of operation. The patients will arrive at a main hub of operation and from there will be distributed to hospitals in that hub aboard C-9's or flown to another regions hub aboard a CRAF aircraft. Each hub will serve a fixed number of hospitals and hospital beds. The patient leaves the transportation system once they are hospitalized in one of the systems 74,725 beds. The key features of the hub system are that it frees the C-141 aircraft to do their primary mission exclusively, and it utilizes the C-9 aircraft more efficiently by reducing the distance between the source of the patients and the hospital location. The system will be exercised utilizing a large scale conventional war in Europe. This size of war will provide enough casualties so that the distribution system will be exercised under a high volume of patients. Daily patient loads will be in excess of 1000 casualties per day.

Measure of Effectiveness

The primary goal of a patient distribution system is to deliver the patients in a timely manner to their destination hospital. Timeliness is needed to ensure that the patients

(C-141). This enables the C-141 aircraft to accomplish their primary force deployment mission in a more effective manner. (24)

The CRAF aircraft are a likely candidate to assume the C-141's air evacuation role because currently there is an under utilization of the CRAF aircraft. CRAF aircraft are often not utilized until adequate equipment is in place overseas. The CRAF are then used to transport the personnel necessary to operate the equipment. In addition the CRAF aircraft (Boeing 747, DC-10, L-1011 and DC-8) have a better environment for the transportation of patients. The C-141 aircraft are very noisy and heating of the cargo compartment cannot always be counted on. Currently 40% of all patients can be carried on CRAF aircraft with no modifications. With some modifications, 100% of the patient categories will be carried.

Scope

The medical air-evacuation of war casualties begins as soon as the patient is airlifted from the battlefield and ends when the patient is safely offloaded at their final hospital. The patient, depending on the situation, might be flown on only one flight straight to their destination hospital near the battlefield. On the other extreme, it may take many flights for the patient to arrive at a hospital in the CONUS. The portion of the system we chose to study begins when the patients first arrive in the United States

focused on developing new MOE's based on a priority of supply categories and shortages of particular supply categories which may give one base priority over another in mission scheduling of tactical airlift. (6:5)

We used LtCol McLain's model and problem formulation as a basic foundation for this study; however, we greatly reduced the scope of the problem to make it more manageable. Because the problem has never been modeled or solved before, we feel, at this stage, a simulation analysis of the problem would be more beneficial than to try to seek optimal solutions of a system that has never been used.

Overview

The capability to evacuate patients successfully during a European scenario war is a necessity. *Exercise PROUD SABER* pointed out that an inability to successfully evacuate patients can be a major war stopper. For these reasons, new approaches need to be explored in order to ensure an efficient and orderly evacuation of patients from Europe to hospitals in the CONUS. The concept proposed by the Operations Research Division at Headquarters MAC is to utilize wide-bodied passenger CRAF aircraft for the strategic aeromedical evacuation. This concept has the potential of improving both force deployment and aeromedical evacuation. Especially important in this concept is the elimination of the already overtaxed strategic aircraft

producing specialized software for a scaled-down version of this model to be operated on the Cray-1 computer. This model is to be completed in 1985. New approaches may be required and new techniques invented to solve the complete patient distribution system. (19)

Simulation has been used to study problems similar to the patient distribution system. Two research efforts were done concerning the modeling of the Noncombatent Evacuation Operation (NEO) in the Federal Republic of Germany. The models used Q-Gert simulation analysis to trace the flight of evacuees from Germany to the United States. The models compared the time required to evacuate American dependents, the transportation assets available and the number of people evacuated. (15)

Although medical evacuation is more complex than NEO, the approach is basically the same. The NEO system is a series of queues, beginning at the evacuees home base and concluding when the vehicle they are on departs Germany. The CONUS patient distribution system is also be a series of queues, beginning at the medical reception area in the CONUS (Dover AFB) and ending when the patient is delivered to a hospital that has a bed corresponding to his injury.

Another simulation study of a transportation problem addressed the problem of developing a measure of effectiveness (MOE) for tactical airlift. This study

directive methods. Both decomposition methods separate the problem into a master problem and a set of network problems for each commodity. However, the methods of price and resource directive procedures are different. In price-directive decompositon, the master problem changes the objective of the subproblems, while in resource-directive decomposition, the master adjusts the right-hand-sides of the subproblems. (19)

Of the three alternatives, Kennington recommends using the resource-directive method for solving a patient distribution system of considerable size. The resource-directive approach remains stable with few commodities (11 patient categories) and requires the shortest computer time of the multi-commodity techniques mentioned. (19)

Kennington's approach to solving the patient distribution problem is indeed promising. However, the patient distribution system is a very detailed system and difficult to solve due to the combinational nature of all the factors. (23:1) In fact, a model of this size has never been solved. The model consists of 9 European recovery bases, 73 U.S. hospitals, 95 cargo loading stations, 11 patient types and 60 one-day time periods. This approach would produce a product with over 100,000 row dimensions and is far beyond the scope of existing computer codes. (23:5) Thus, Dr. Kennington, under contract from Headquarters MAC, is in the process of

the number of destinations increase the computational complexity increases greatly.

Ferguson and Dantzig present a linear programming model for assigning aircraft to routes. Their model assumes no fixed charges. (13) In a related study, Bellmore presented a model for assigning tankers to shipping routes in an attempt to maximize a utility function. The routes were assumed given and no fixed charges were incurred in the shipping process. The tankers are viewed as commodities and can be loaded after assignment to a specific route. (4)

In discussing possible approaches to solving the patient distribution system problem, LtCol McLain proposed a multicommodity approach to the aeromedical evacuation problem. This approach would model the current C-141 and C-9 patient distribution system using network theory by combining a vehicle routing problem with a patient network flow problem. The categories of the patients represent the multiple commodities.

Further research into multi-commodity network flow problems points to a possible solution of the patient distribution system using either the technique of partitioning or decomposition. Partitioning seeks to exploit the structure of multi-commodity network flow problems by means of basis partitioning so that portions of each basis will be lower triangular. Decomposition can be accomplished using either price-directive or resource-

these medical models and ensure medical plans can be adequately supported. Depending on the criticality of the time patients are in this distribution system, the level of air transportation could possibly affect medical plans for the locations and uses of various medical facilities and concepts in handling patient injury categories. Together, these models can ensure MAC and the Medical Service will accomplish their role of maintaining our fighting force during a war-time crisis.

Previous Analyses Related to Problem

The problem of distributing patients in a network of CONUS hospitals is a major routing and scheduling problem. Many charcteristics of the patient distribution system are also seen in the areas of routing buses, commercial aircraft and ships.

The routing of a school bus is concerned with a single period of time and a single destination, the school. Typically problems of this type can be solved with a heuristic method based on a modification of the nearest unvisited city in the traveling salesman problem. (1) In another study, a two phase approach for developing schedules for city buses was developed. The first phase obtained a set of potential routes for the buses. The second phase gave the frequency of travel. (30) Both of these techniques initially appeared promising; however, as

However, there is a congressionally mandated requirement to study the current air transportation medical evacuation system to ensure medical plans can be supported. Also, filling the gap in aircraft shortages for aeromedical evacuation may result only after a comprehensive study is done in conjunction with these tri-service computer models. A study of this nature could also provide a data base for this model to include air transportation or remain as a stand-alone model of the patient distribution system.

To this end, the Military Airlift Command contracted with Southern Methodist University for a study of the capability of the C-141 and C-9 aircraft to support the medical evacuation requirements along with their other military airlift missions. Although this study is not completed, an alternative plan suggested by MAC is to use Civil Reserve Air Fleet (CRAF) aircraft dedicated solely to the aeromedical evacuation mission. This approach to the problem has not been studied yet and forms the basis for this study.

There are many anticipated applications of these models in the future by the Air Staff, MAC, and Office of the Surgeon General in the area of requirements determination and analysis. The models will aid in planning and making better decisions based on more quantitative, accurate information. A patient distribution system model based on MAC's aeromedical airlift capabilities would complement

destinations throughout the United States. At these destinations the patients must be off-loaded immediately and the plane loaded with war supplies and launched as quickly as possible. If the locations coincide with a suitable hospital or a medical staging area (a place where patients can be temporarily held but not extensively treated) the paients will be taken there; otherwise, a C-9 aircraft must arrive in time for a direct plane-to-plane patient transfer from the C-141. These predetermined itineraries cannot be altered to transit other bases to deliver patients as the schedule is determined by another planning system which gives priority to cargo, and not patient movement. (23:3)

In an attempt to confront this problem, Congress directed there be more commonality between the services in medical care, and the Assistant Secretary of Defense for Health Affairs initiated the development of a tri-service contingency medical computer model for future medical wartime planning. So important are these models, that Congressional appropriations for increased DOD wartime medical systems are tied directly to studies resulting from the tri-service models. (18:30)

The Air Force has a significant role to ensure commonality in the medical systems and must also ensure model logic is applicable to all AF medical systems. The models, to date, have not been expanded to include an aeromedical evacuation patient distribution system.

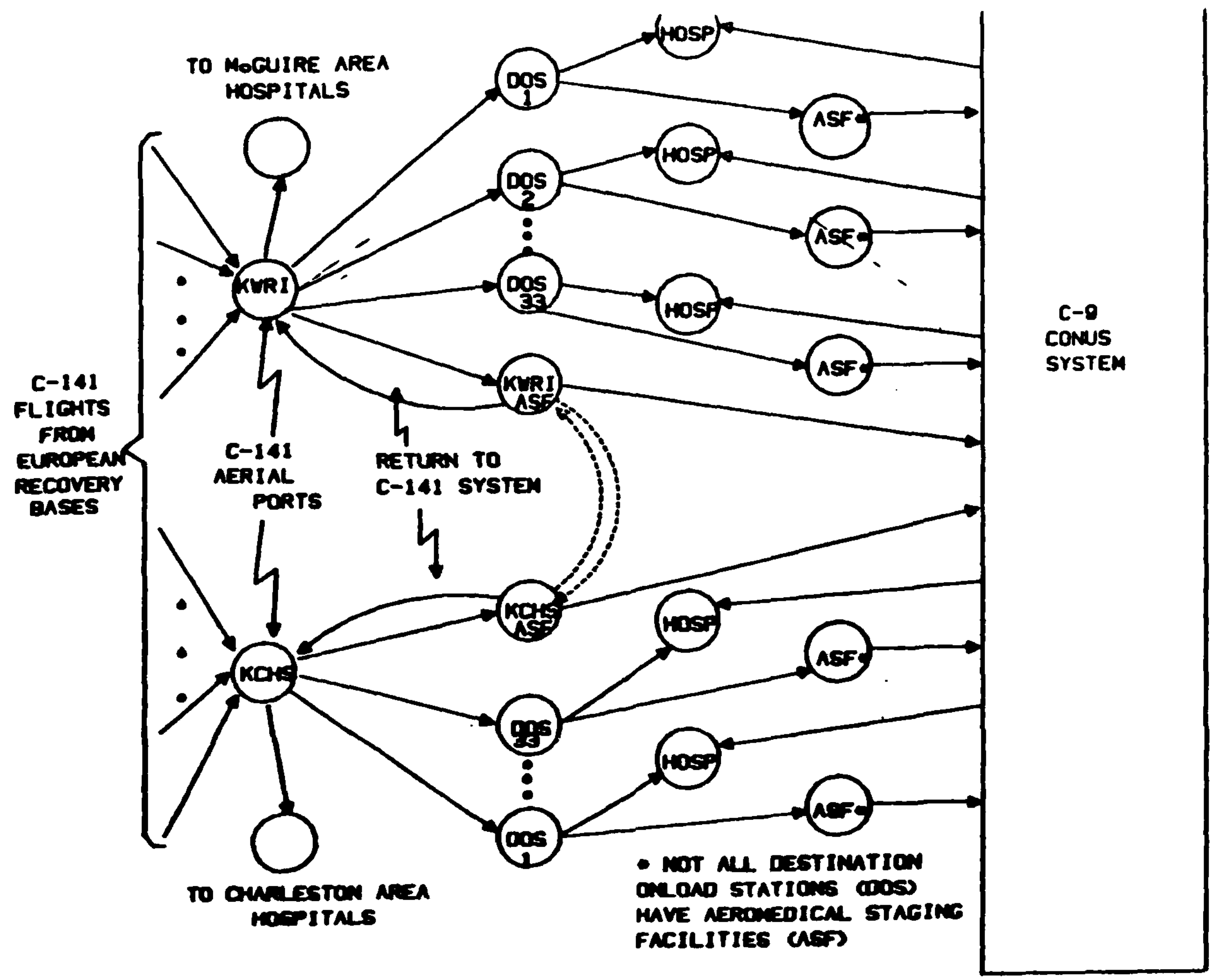


FIGURE 2. PRESENT PATIENT DISTRIBUTION SYSTEM

CIVILIAN-MILITARY CONTINGENCY HOSPITAL SYSTEM

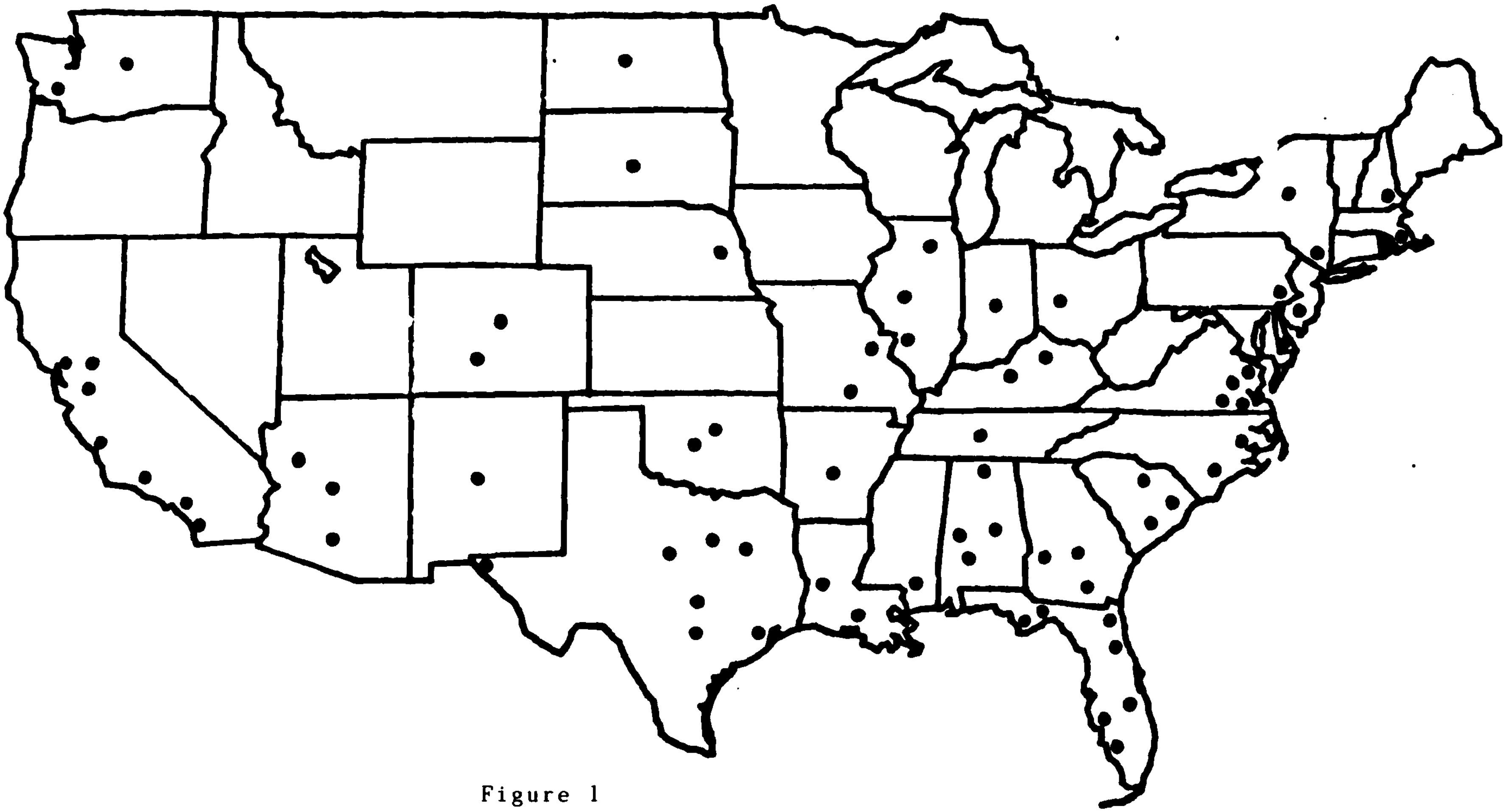


Figure 1

portion of the strategic aeromedical evacuation plan. Current evacuation plans call for patients to enter the Strategic aeromedical evacuation system at recovery bases (one of any nine) in the theater aboard C-141 aircraft. To avoid repositioning aeromedical assets of the C-141 fleet in Europe, a surge capability concept for the first 30 days of a theater conflict was instituted. This removed the requirement for airline-type seats, comfort pallets, and increased the patient load limits. Increases in aeromedical evacuation crews in the FY 82-86 Program Objective Memorandum are anticipated to meet the expected demand for strategic patient movement. (8)

To increase the number of beds available in the CONUS, a civilian-military contingency hospital system (CMCHS) was developed. In this system civilian hospitals, located around a focal point military facility, commit a given number of beds during wartime. There are 73 CMCHS which add over 74,000 beds to the CONUS medical care system (see Figure 1). (8)

The matching of C-141 bases and their pick-up points in the CONUS with the potential sources of medical care in the U. S. has been of concern to the Military Readiness Division. The present system calls for the MAC C-141 fleet to deliver patients throughout the U. S. in conjunction with their military airlift mission (see Figure 2). That is, the C-141's have predetermined itineraries to onload

aeromedical evacuation mission. This system would also use C-9s but would free up the C-141s for their primary mission.

This study uses that CRAF concept in developing a CONUS casualty distribution system. Based on a HUB-and-spoke approach to distributing the patients, this system attempts to minimize the average time the patients are in the transportation system by effeciently utilizing aircraft resources while reducing patient back logs and excessive delays.

II. SYSTEM DEFINITION AND MODEL FORMULATION

Introduction

There are many complex interactions involved in any patient distribution system. The method of distribution must be able to sort through the system for a given time period and predict the number of hospital beds available. If no beds are available then the patient must be put in a temporary holding area. In addition, the distribution system must be able to determine the appropriate network routing so the patients spend minimal time in the system and the aircraft are efficiently and effectively utilized.

The system developed in this study is an alternative approach to the problem of distributing wartime casualties. The approach is new in that 1) the CRAF is used to fly the casualties in conjunction with the C-9s, 2) the route structure and scheduling philosophy is different, and 3) the methodolgy involves the use of simulation to model the network. This simulation study provides an evaluation of the patient distribution system based on a macro level of analysis.

Simulation provides an approach to analyze the performance of this patient distribution system problem under war-time conditions. According to Pritsker and Pegden, simulation is "... the representation of the dynamic behavior of the system by moving it from state to state in accordance with well defined operating rules." (27:6) The

framework of this study's model model rests on discrete simulation concepts. The problem is particularly suited for discrete simulation because the state of the system changes at particular event times. These times are: 1) the arrival of patients into the system at Dover, 2) scheduling of aircraft to fly, 3) arrival of patients into their final hospital and 4) the discharge of patients out of the hospital. If none of these events are occuring then the system is in an equilibrium. Simulation is also a valuable tool when the mathematical formulation is complex. (28:11) The complexity of the current patient distribution system illustrates this.

Using Shannon's concept of world view, the process is summarized as follows (28):

1) The world is viewed as a set of patients that are characterized by their patient category.

2) The entities interact with the specific activities of either flying or waiting for a bed. This flying or waiting for a bed is consistent with the conditions of having beds available through patient discharge.

3) These interactions of the patients with the events of the system result in the changes of state in the system.

The patient distribution approach is based on a HUB system. The rationale is that it is more efficient to route the patients to a centralized location among the many hospitals and then distribute them by category, than to distribute them directly from their arrival point in the CONUS to the hospitals. For the purposes of this study, the rationale or validity of the HUB system will not be compared to other potential systems. Rather, the modeled HUB system is used to screen the factors within this system and can concentrate on these factors for more in-depth analysis. The purpose is not to find an optimal solution, but rather, to gain insight into the problem and to show how the system flexes under different policies.

The simulation model will be useful for studying the distribution system operation under various arrival rates, bed availabilities, patient mixes, aircraft sizes and mixes, etc. It will also be useful for understanding specific problems in the system such as bottlenecks, aircraft or bed shortages, etc. Once expanded and with other distribution systems modeled, comparisons of the various systems can be made.

Scenario

The scenario used for this study is that of an intense conventional war in Europe. Basically, it represents the same scenario used by the Medical Readiness Division in their tri-service computer models. "This scenario is limited in two aspects: it ignores the potential use of biological, chemical and nuclear weapons and ignores the effects of waging war in other areas of the world and the medical ramifications of geographic conditions, such as terrain, climate, distances involved and different indigenous diseases in these areas." (18:31)

The study will analyze the distribution of casualties for a 60 day period. The assumption made is that the number of casualties and their arrival rate into the CONUS during the first 60 days of an intensive conventional war in Europe will be the limiting factor in aircraft requirements. The actual estimated number of casualties generated by this type of war is classified data. However, even unclassified estimates are staggering: "Any large scale conflict involving U. S. Armed Forces operating under NATO and European Command (EURCOM) will generate tens of thousands of casualties." (23:1)

Because classified data could not be used and MAC war plans were not accessible for estimating the number and frequency of returning flights carrying casualities, the number of patients arriving in the CONUS had to be

approximated for this study. After discussing this problem with the Medical Readiness Division and MAC's Operations Research Branch, it was determined that approximately 1000 patients arriving in the CONUS each day to be a reasonable assumption. Transporting over 60,000 patients to their respective hospital bed locations throughout the CONUS would give a good indication of how this alternative patient distribution system works.

In terms of aircraft available, it will be assumed the C-141 cannot support the aeromedical evacuation system in the CONUS as planned. Thus, civil reserve air fleet (DC-8, B747, DC-10 or L1011) will be used. Because there are no CRAF aircraft currently equipped for aeromedical evacuation (studies are now in progress), the particular type of aircraft is not important. For this study, the CRAF aircraft is a generic aircraft distinguished only by its estimated capacity. These aircraft will be dedicated solely to the CONUS portion of the aeromedical evacuation mission in conjunction with the military C-9 aircraft (or an aircraft of equivalent capacity).

Casualty Characteristics

Currently, the Medical Readiness Division classifies war casualties into 309 separate categories for medical treatment. (9) These categories are consolidated by the Military Airlift Command into 11 categories for aeromedical evacution purposes and for assigning casualties to hospital

beds in the CONUS (see Appendix A-1). Each category of patient must be matched to a respective type hospital bed (the bed types indicate that the medical staff and facilities are available to care for that type of casualty). Each patient category also has a length of hospital stay associated with it. This represents the time that a respective bed will be occupied before it becomes available for use by another patient of that category. The patient categories, by percentage of total patients expected and the respective hospital stays (LOS), are given in Table I (data obtained from MAC Operations Research Division and the Medical Readiness Division):

Table I

Casualty Characteristics

TYPE	PERCENTAGE	LOS (Days)
1) Medical (MIM)	20 %	16
2) Psychiatric (OPG)	7 %	29
3) General Surgery (SGS)	31 %	24
4) Orthopedic Surgery (SOR)	19 %	50
5) Neurosurgery (SNS)	6 %	36
6) Oral/Maxillo Facial (SMF)	7 %	40
7) Urology (SUR)	1 %	12
8) Opthamology (SOP)	3 %	27
9) Burns (SBN)	2 %	33
10) Thoracic Surgery (STH)	4 %	54
11) Spinal Cord (SCI)	<< 1 %	38

To simplify the simulation model, yet maintain the complexity of the scheduling problem for the various types of patients, the patient categories needed to be further condensed. To do this, both the percentage of a patient category and the length of hospital stay had to be considered. After analyzing a series of histograms of the above data, all the types with less than five percent of the total patients were put together. Since their length of stay varied considerably, probabilistic branching within the SLAM network was chosen to assign their actual length of stay. Thus CAT I patients are made up of the following categories (length of stays are converted to weeks since that is how the model accounts for this factor):

Table II

Patient Category I Description

			Sub Type	% of Total	LOS
CAT I (10%)	=>	11)	Spinal Cord	0 %	6
		7)	Urology	1 %	2
		9)	Burns	2 %	5
		8)	Opthamology	3 %	4
		10)	Thoracic Surgery	4 %	8

Next, categories with similar percentages of total patients and similar length of hospital stays were evaluated. Because there was only a one percent difference in amount,

these three categories were grouped together. One of the categories had a length of stay one week less than the other two (see Table III); extending those patients one extra week would not appreciably affect the outcome of our analysis. Thus, CAT II patients are made up of the following and considered as one overall category:

Table III

Patient Category II Description

		Sub Type	(Previous % Total / LOS)
CAT II	5)	Neurosurgery	6% / 6 weeks
(20% / 6 weeks)	2)	Psychiatric	7% / 5 weeks
	6)	Oral/Maxiallo Facial	7% / 6 weeks

The following categories are large enough to maintain their respective identities.

Table IV

Patient Categories III, IV, V Description

CAT III (19% / 8 weeks)	4)	Orthopedic
CAT IV (20% / 4 weeks)	1)	Medical
CAT V (31% / 4 weeks)	3)	General Surgery

Although not yet validated, the five major categories appear to be grouped and ordered by similar medical

priority. In discussion with medical personnel, one can not generalize about the categories. There will always be a case where one patient in one category has a higher priority than a patient in another category. (29) Thus no attempt was made to prioritize patient loads. Patients were loaded starting with category one on a first-in-first-out basis. These patient classifications appear sound for the objectives of this study.

The length of stays for each patient category was converted into weeks. The system accounts for the length of stay of each patient category by monitoring the number of every category patient that enters each hospital each week. The patients are then assigned that bed for the specified number of weeks. At the end of every week, the patients are moved one week closer to being discharged. When the patients week to be discharged becomes the current week, the patients are discharged uniformily over the seven day period--opening up their respective category beds for new patients. This procedure encorporates some degree of variability for the patients length of stay within the system.

Route Structure

Network analysis has made important contributions to the study of transportation systems. (16:232) The route structure for a possible patient distribution system proposed by MAC Operations Research Division encorporated a

HUB system based on network theory. This HUB system would be similar to that used by express package delivery companies such as Federal Express. To find the locations of these HUBs in the CONUS, the hospital locations (73 CMCHS locations, see Figure 1) are input into a network theory algorithm. This algorithm uses multi-source Weber theory (also called moment sum approach) which enables one to find central locations in a cluster of points based on Euclidean distances. (25)

This algorithm finds from one to ten hub locations which minimizes the total out and back distances between the HUB locations and their respective destinations. After qualitatively examining the alternative number of HUBs based on the 73 CMCHS locations, a three HUB model was selected to analyze as an alternative distribution system. Because of the limited number of C-9 aircraft available to distribute the patients, MAC needs a distribution system which maximizes their effective use--that is, a system which minimizes the total time the C-9s fly without carring patients and enable the aircraft to go to the most hospital locations without exceeding the crew's duty day (16 hours) or sortie limit (five sorties). The geographical layout of the three HUB model appeared to be the best suited for this application. Based on this algorithm, the three HUB locations selected were Dover AFB, Delaware, Maxwell AFB, Alabama, and March AFB, California.

The casualty arrival point is represented as Dover AFB--a logical point to refuel, get maintenance, and change crews after an overseas mission. Medical and morgue facilities are also available. This also represents the location where the patients would be transferred to CRAF aircraft or C-9 aircraft. Maxwell and March both have regional medical facilities. These HUB hospitals will serve as staging facilities with increased medical capabilities established on a temporary basis for the duration of the war.

To further approximate the most efficient route structure, this system encorporated a spoke system for each region based on the geographical locations of the hospitals within each region (see Figure 3 and Appendix A-2). Thus, a C-9 which enters a specific spoke in a region can only "fly" to hospitals in that particular spoke. The aircraft must return to the HUB hospital to pick up more patients before it is able to fly another mission in the same spoke or proceed to another spoke. Although the C-9s in many cases will fly to more than just one hospital in a spoke before it returns to the HUB hospital, the geographical layout of the spokes combined with the large number of C-9s that will be filled to capacity and fly to only one hospital before returning to the HUB justifies using Weber theory to locate approximate ideal locations for the HUBs. An interesting observation to note is that for a single HUB system for the

ALTERNATIVE CONUS CASUALTY DISTRIBUTION SYSTEM

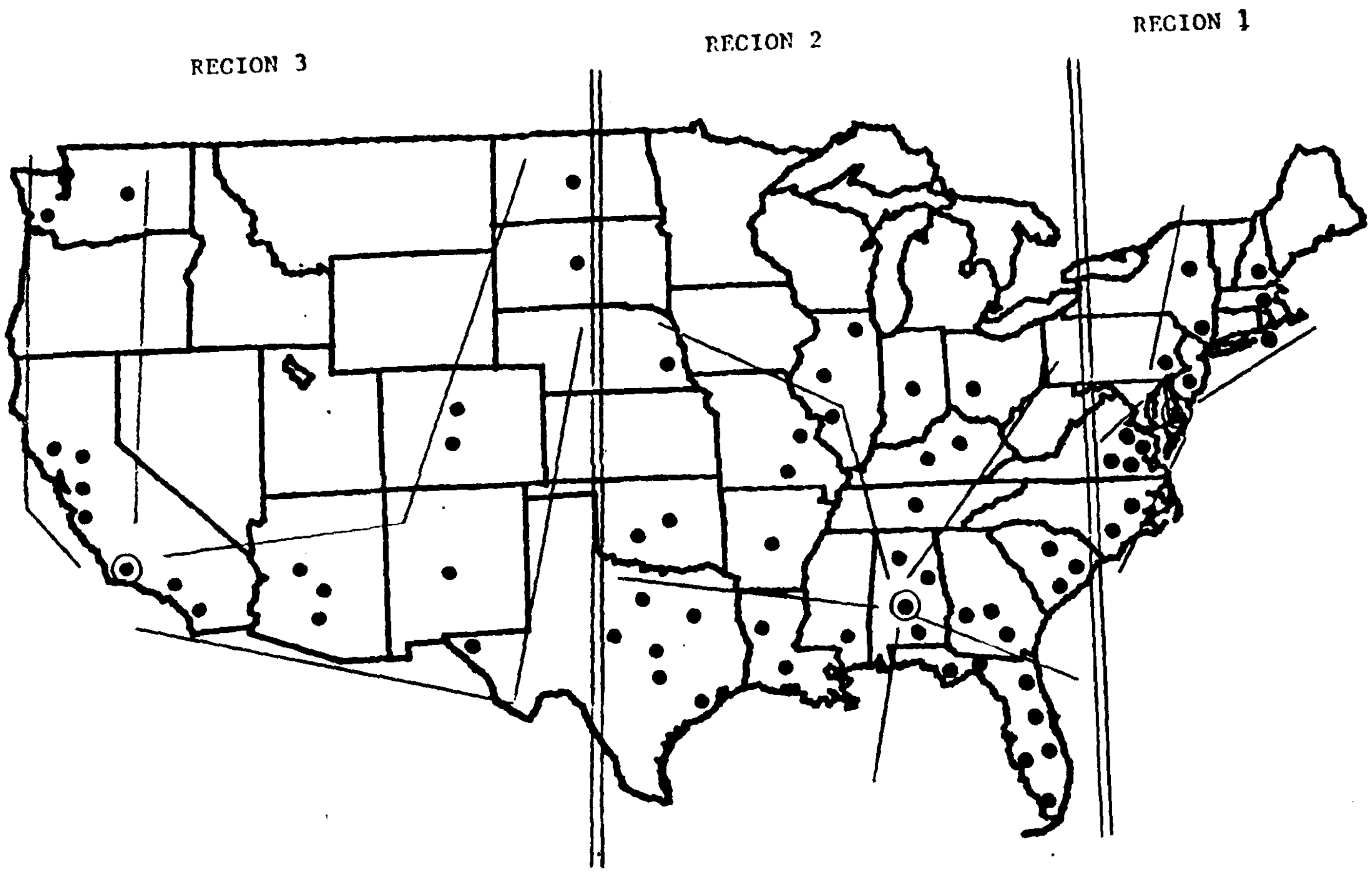


Figure 3

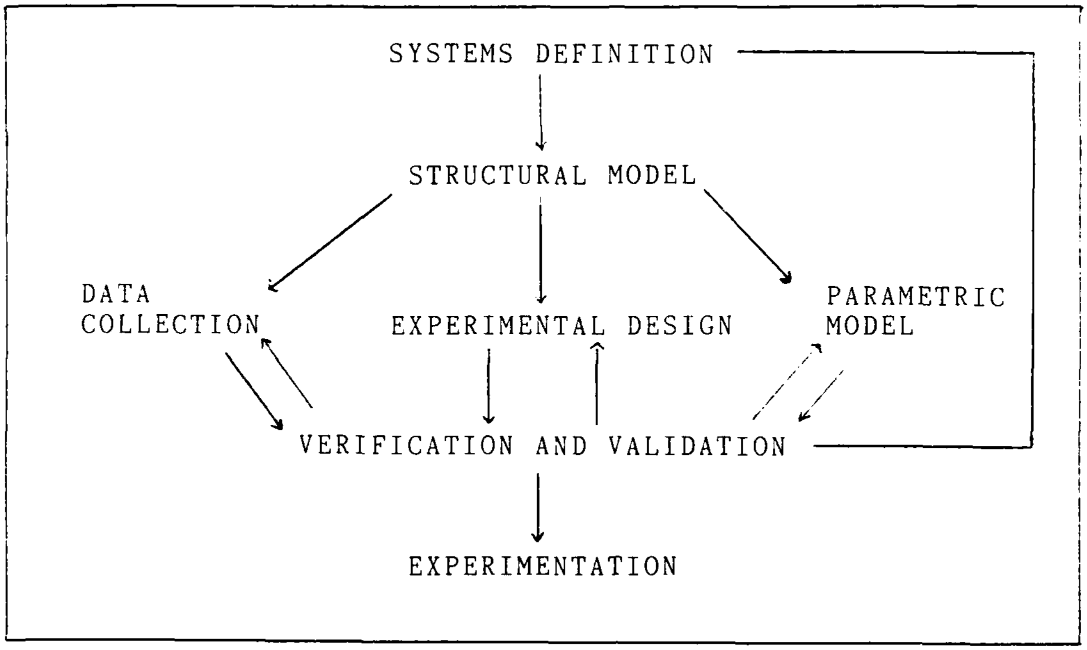
CONUS based on the 73 CMCHSs (the majority of these locations correspond to major cities throughout the United States), the HUB was computed to be Memphis, Tennessee--the same location Federal Express uses for their HUB system.

The distances between the hospitals in each spoke are accounted for by accessing a data file in the model which has the computed distances between all the hospitals based on a great circle distance calculation using longitude and latitude coordinates (see Appendix B for code). (25) Flight times between hospitals are calculated by dividing the distance between the hospitals by the appropriate block speed for that distance as obtained from MAC Reg 78-2, Aircraft Planning Factors. Block speed is defined as the average speed used to calculate time from takeoff to parking for a specified range of distance.

As this is an initial study of an alternate patient distribution system, the system was modeled as a perfect system. That is, there are no takeoff delays, aircraft reliability is assumed to be 100 percent, and any maintenance or refueling can be accomplished in the alloted average ground times (three hours, fifteen minutes for the CRAF; two hours for the C-9 at the HUB, one hour at enroute stops). Surface transportation from the aircraft to the hospitals is not included in the model.

FIGURE 5

Process Analysis



The model of the system developed is a sound one conceptually. With all steps of the process complete, the feedback loop to the top of the process analysis was needed. The concept of using dedicated CRAF to distribute casualties to CONUS hospitals should provide a method that provides an efficient and orderly delivery of the patients. With this idea in mind initial data runs were accomplished to see how the model met the concept of the system.

Initial Data Runs

On the first complete run of the model it was noted that the category three patients (orthopedic) had an average time in system a magnitude greater than the other four

3) Internal Validity - replications were accomplished on the stochastic model to determine the stochastic variability in the model.

4) Parameter Variability / Sensitivity Analysis - input and internal parameters were changed. The results were examined along with the effects on the model and its output. Small iterative changes were made on the model to ensure its correctness. All outputs appeared reasonable over all ranges of changes in input and internal parameters.

5) Structural Assumptions - based on prior experience in strategic airlift and conversations with MAC analysts, structural assumptions of the model appear validated.

However, the model lacks total validity because no historical data exists or is there a real system to compare the model to (as the system is a new proposal). If there was, further validation of the model could be accomplished by comparing the model to existing models; use historical data to see if the model behaves the same as the real system; see if the events of occurrences in the model coincide with events of the real system; apply turing tests of the output of the model; make predictive validation by running the real system under the model's parameters; and compare input-output transformations of the real - modeled systems.

The Iterative Process Analysis

The concept of process analysis can be seen in Figure 5 below. (11) As can be seen from the figure, process analysis is a continuing process always returning back to the definition of the system.

as structured programming. In addition there was consultation with others (our thesis advisor who critiqued logic and programming methods while being detached from the daily involvement of the process). Throughout the program values of variables were printed and a slam trace was used to monitor the progress of the program. Using these techniques the following kinds of verification were accomplished. (5:9)

1) Manual verification of logic - the computer model was run for a short period and also followed through by hand calculations. Both results were similar.

2) Modular testing - to as great extent as possible each subroutine was tested separately to verify output before inclusion in the model.

3) Sensitivity testing - just one parameter was varied while keeping the others fixed (such as arrival rates, distributions, type aircraft, number of beds, etc.) and checked that the behavior of the model was as expected.

4) Stress testing - the parameters were set to unusual values to test extremes of the system and all possible situations. For example, the available beds were made small and the patient arrivals large to see if the system blew up in a reasonable fashion. It was also decided to test all possible aircraft scheduling combinations to ensure flight times and patient delays were calculated correctly.

Validation

Many validation tests were applied for this project: (21:162-163)

1) Face Validity - the results of the model appear reasonable. The model was formulated based on information received from HQ MAC XPSR and in conjunction with our thesis advisor. Thus the model appears reasonable.

2) Traces / Graphic displays - the computer model was checked to ensure the model's logic and the computer program were correct. Both the trace method and a step-by-step printout of computed variables were utilized throughout the program.

other model parameters (i.e. beds, number of hospitals, etc.). Thus the parameters can be estimated as illustrated in Table V.

TABLE V

Estimates of Parameters

$$E(X) = (a + b + c) / 3$$

$$(160 + 190 + 200) / 3 = 183.33 \text{ [HI]}$$

$$(160 + 175 + 200) / 3 = 178.33 \text{ [LOW]}$$

$$\text{Mode} = 3\,E(X)-(a + b)$$

$$3(183.33) - (160 + 200) = 189.99 \text{ [HI]}$$

$$3(178.33) - (160 + 200) = 174.99 \text{ [LOW]}$$

The variance, V(X), of the triangular distribution is of little use to the analyst. (3:158)

Verification

Computerized model verification (checking to ensure simulation program operates as intended) and conceptual model validation (checking that the simulation model, correctly implemented, is a sufficiently close approximation to reality for the intended purpose) is essential to any simulation analysis. The process of verification and validation was inherent throughout the study of the problem and formulation of the model.

In developing the computer model (both SLAM and FORTRAN) standard computer debugging techniques were applied as well

arrivals into the U.S., occurs because lack of actual data and classification of some of the data. During peak periods of the 60 day war there will be approximately 1000 patients arriving per day. For these reasons the triangular distribution was selected. Banks and Carson suggest using it in cases when there is limited or incomplete data available. Given the limited data, the triangular distributions represents a good assumption. (3:134)

The distribution of beds during the war was analyzed by breaking the 60 day war bed data into 10 day increments of time. In ploting histograms of how the beds were distributed, it was noted that generally the number of beds in each hospital, per category, increases as the war progresses. The actual increase in beds from day one to day 60 was 10 percent. For this reason, the bed data was held constant during the war. The actual number of beds projected for day 30 of the war was used because it represented the average number of beds available at the hospitals.

For the number of patients arriving, 1000 patients per day was selected as a representative number. The high mode selected was 190 patients in the triangular distribution with 160 and 200 as the end points; the low mode selected was 175 patients. It was felt these two extremes would represent good high and low patient loads relative to the

with modes of 190 high and 175 low. These numbers were picked as representative numbers of patients arriving during any one period of time. For example, the arrival of 160 patients could represent the arrival of three C-141 aircraft from Europe or one Boeing 747. In addition, the range of the number of arriving patients had to be selected carefully so the system would not "blow-up". It was felt that useful policy analysis would not be possible in an oversaturated system.

The raw data available for the number of beds, on the other hand was very specific. The Operations Research Division at Headquarters MAC has computer tapes of projected bed availabilities for each day of the war. In general, the number of beds available in any hospital increases or remains the same as the number of beds available on the first day of the war. The reason for this phenomena is that time is required to mobilize the medical crews.

As was mentioned above the distribution of casualties was assumed to be triangular between 160 and 200. On visiting Headquarters MAC some insight was gained into the actual distribution of the arriving patients during the war. LtCol McLain expects the distribution to be exponential with time. As the war begins, initially there are only a few patients arriving. However, the Medical Readiness Division expects a more level rate of casualties. The differing estimates, on the statistical distribution of patient

III. MEASUREMENT AND DESIGN

Data Collection and Analysis

The input data for the simulation consists of serial input from outside the systems environment. The input to the system occurs at Dover AFB, where the casualties arrive from Europe on aircraft. The two input factors that drive the simulation are the number of patients that arrive and the time between arrivals of the patients. Another important factor is the number of beds that are available for the arriving patients. Both of these factors will be discussed below using the steps that Banks outlined for the development of valid input model data. The steps are: 1) collection of raw data, 2) identification of the underlying statistical distribution, and 3) estimation of parameters.

A lot of empirical data of casualty numbers and arrival rates are available from the Korean and Vietnam wars. However, these were both long, drawn out wars; untypical of what MAC and the Medical Readiness Division expect in a European conflict. Thus, it was important in selecting input data for the model to use a theoretical distribution for the number of casualties and the arrival rates of the casualties into the United States. It was not possible to collect any physical data in this case because there has not been a large scale European war since World War II. The distribution chosen to represent the stochastic nature of patients arriving in the CONUS is triangular from 160 to 200

using a scenario representing an intense European conventional war. Casualties arrive in the CONUS at an estimated rate of approximately 1000 patients per day for a 60 day war. The casualties are transported aboard aircraft according to eleven aeromedical evacuation categories based on their type of injury. For this study, the eleven categories were further reduced to five by aggregating categories with similar characteristics. To receive medical treatment in the CONUS, the casualties can only be transported to hospital beds which match their category type.

To distribute these patients, a three-HUB distribution system was developed--a northeast region using Dover AFB as the HUB, a central and southeast region using Maxwell AFB as the HUB, and a western region using March AFB as the HUB. The HUBs were calculated based on a moment-sum network algorithm that finds central locations among many destinations. An approach used by Federal Express in locating their central HUB of operations. The system was developed to effectively and efficiently utilize the C-9 aircraft within the regions, and to use CRAF aircraft to transport patients between regions. The scheduling philosophy is to fill up the closest region to the CONUS arrival point first (northeast region) and then transport the patients to the next closest region.

and can all be delivered to Spoke 2; but there are still a few beds available in Spoke 1. Two aircraft will be scheduled to fly the patients--one to carry the few patients to fill up Spoke 1 and another to carry the remaining patients to Spoke 2.

The reason the algorithm does not treat these situations differently is because this study is not meant to analyse a sortie-by-sortie account of aircraft usage, but rather to gain insights into aircraft requirements on a macro level. The main assumption of the casualty distribution system is that the available beds in the system will be overloaded. The requirement for CRAF aircraft will not be influenced by the few flights where patients trickle from region to region, but rather when one region is just about completely filled and the majority of incoming patients must fly to another region for beds (the maximum utilization period for the CRAF). In the case of the C-9 situation, since it is assumed all the beds in a region will be filled up, this algorithm will closely approximate the required number of sorties and average patient time in the system to fill the entire region. Also, the peak periods of demand will dictate C-9 aircraft requirements.

Summary

The proposed patient distribution system was modeled and computerized using both SLAM (a computer simulation language) and FORTRAN computer code. The system is analyzed

to the HUB hospital so as not to exceed any limitation. Once a spoke is filled or there are no more beds of a particular category, the C-9s are scheduled to fly through the next spoke.

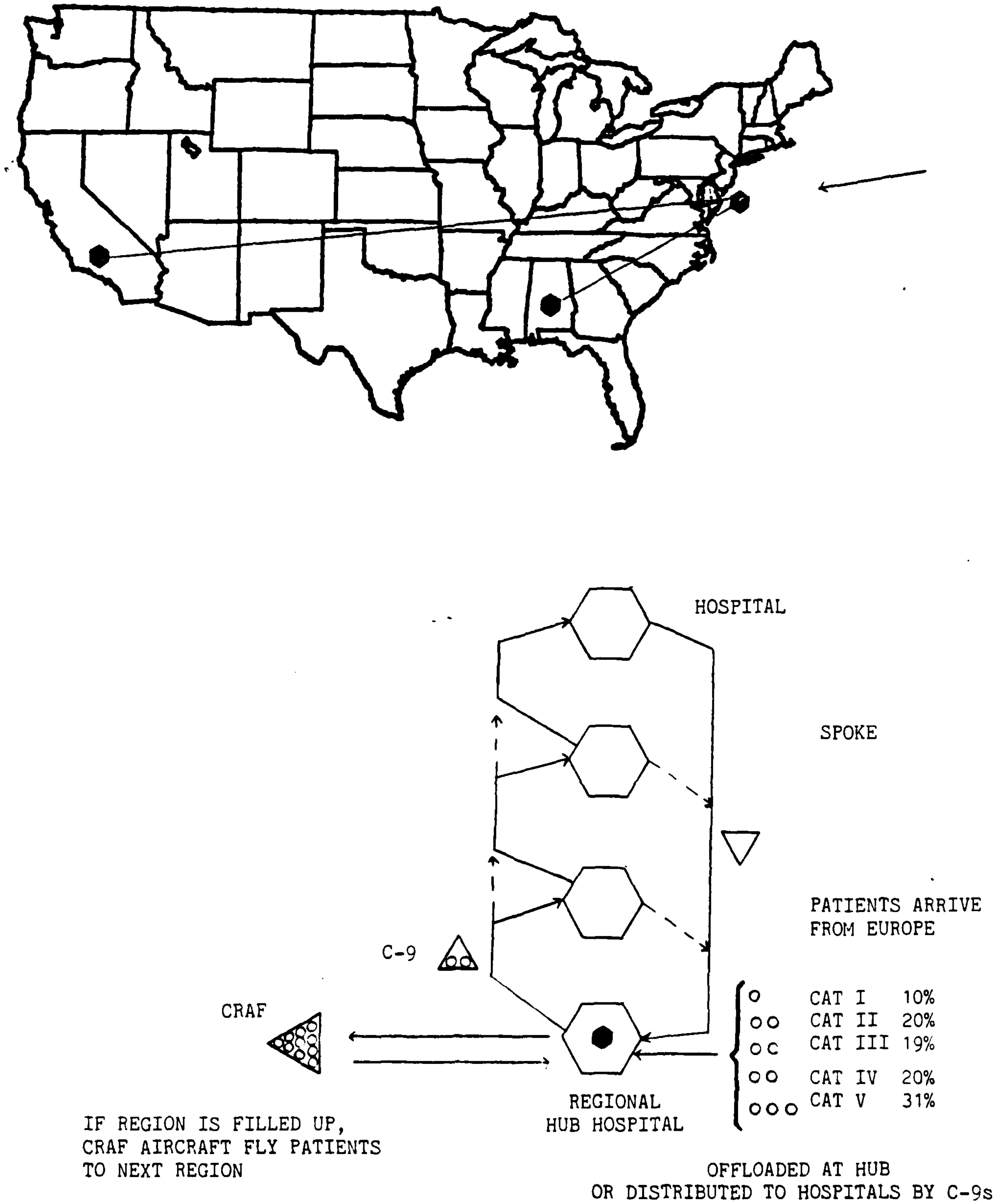
If beds are not available for the patients in Region 1, then a CRAF aircraft is loaded and flown to the nearest region (Region 2) with beds available. The identical process of distributing patients that occurred in Region 1, is initiated in the region the CRAF flys to. Likewise, when beds run out in both Region 1 and Region 2, a CRAF aircraft is loaded and flown to Region 3. Once patients arrive at their destination hospital (offloaded from the aircraft), their time is again recorded and an elapsed time of each patient from entry into the CONUS to destination hospital is computed.

The algorithm allows all scheduled events to occur simultaneously as if in real time. That is, CRAF aircraft and C-9s can be flying at the same time if patient loads dictate that requirement.

There are some obvious inefficiencies in this scheduling algorithm. For example, the only way for patients to get from Region 1 to Region 2 or 3 is by a CRAF aircraft. If only a few patients needed to get to Region 2, the CRAF would be grossly the wrong choice of aircraft. Another inefficiency may develop when the C-9s fly the spokes. For example, 40 patients are at the HUB hospital

STRUCTURAL DIAGRAM

Figure 4



schedule the aircraft in every situation, it does provide a close approximation for the objectives of this study (see Figure 4 for structural model depiction).

Initially when the patients arrive at the HUB hospital of the first region (Dover AFB), the algorithm records the arrival time for each patient, sorts them by category, and distributes them at the HUB hospital if beds are available of their category-type. If patients are still remaining, the algorithm scans Region 1 for the proper category beds. The C-9 aircraft are then scheduled to fly the patients to their respective hospitals. The aircraft are loaded by starting with the nearest hospital and trying to fill up the aircraft with patients for that hospital starting with category one.

The algorithm accomplishes this by starting at the HUB hospital and "flying" through a spoke. The algorithm looks ahead one hospital at a time, comparing each category of bed with the patients remaining at the hub. If there are no patients for a particular hospital or no appropriate beds at a particular hospital, the algorithm will skip that hospital and look ahead to next hospital. Throughout this procedure, the algorithm keeps track of aircraft capacity, total sorties, crew duty day (cumulative time to farthest hospital the aircraft has patients for, plus the return time from that hospital back to the HUB hospital), and the location in the spoke. If any limitation is or will be exceeded, the algorithm schedules another aircraft or returns the aircraft

aeromedical evacuation. The C-9s will be scheduled to fly to the closest hospitals in Region 1 first. Because this is a wartime scenario, the aircraft and hospitals will be loaded to capacity. Thus, the C-9s will all be initially utilized in Region 1 and should be based accordingly.

When there are no more beds of a particular category in Region 1, the patients will be flown to the HUB hospital of the closest region with available beds (Region 2 at the start of the war) aboard an appropriate size aircraft (C-9 or CRAF). The same C-9 scheduling policy applies in Region 2 as in Region 1. As the beds in Region 1 fill up, the aeromedical evacuation command center will move more and more C-9's from the Region 1 HUB to the Region 2 HUB. However, even after Region 1 is filled up, some C-9s will be needed at Region 1's HUB to transport patients to beds which become available during the course of the war due to patient discharges. The same procedures will be followed as Region 2 fills up. Patients must then be routed from Region 1 to Region 3.

Scheduling Algorithm

The aircraft scheduling algorithm must be completely self-contained in the model because the SLAM-FORTRAN computer code is non-interactive. That is, there is no human interaction overseeing the scheduling for the total duration of the war. Although this algorithm does not represent the actual manner in which a scheduler might

Proposed System Scheduling Policy

Because of the combinational complexity of matching 11 categories of patients with their respective bed types across the CONUS, it is not possible to account for every scheduling possibility. Therefore, a general overall "philosophy" of CONUS wartime scheduling must be implemented--realizing there will always be cases where an exception to this scheduling policy may be more efficient. In these cases prudent scheduling should take over. The description that follows is what was envisioned as the overall scheduling philosophy of a three HUB casualty distribution system during wartime.

Patients will arrive into the CONUS at designated medical reception areas. The existing plan uses McGuire AFB, New Jersey and Charleston AFB, South Carolina. A location such as McGuire AFB or Dover AFB is envisioned as one medical reception area (corresponding to this model's Region 1 HUB hospital). However, if CRAF are used to return patients directly from Europe, the CRAF may fly to the HUB hospital of Region 1 or directly to the HUB hospital of Region 2. For this study, all arrivals into Region 1's HUB hospital, Dover AFB, were modeled.

At Dover, patients will be placed in hospitals if beds are available or disbursed to nearby hospitals using ground transportation. If not, medical personnel will prioritize the patients according to triage requirements for

categories. The category three patients account for 19 percent of each arriving load of patients. In contrast to this, the category three beds are only approximately 10 percent of the total available number of beds. This leads to a problem when the system is saturated to just below capacity, because there is not any room in the system for the category three patients. Another important factor for the category three patients is their length of stay in the hospital. The category three patients spend eight weeks in the hospital. Therefore, once a category three patient enters the hospital, the bed remains full for the duration of the 60 day war. On the other extreme, the category four patients comprise approximately 20 percent of each arriving load of patients; however, the number of beds in the system for category four patients is 40 percent of the total beds. The length of stay for the category four patient is four weeks. Because of the combination of many beds and short hospital stays, the category four patients beds were never filled.

Prior to making additional pilot runs it was assumed that beds would be made available for the category three patients. This was accomplished by decreasing category four beds in each hospital by 14% and increasing the category three beds by the decrease in the category four beds. With this assumption, the time in system for all categories was of similar magnitude.

Variance Reduction

Autocorrelation in the patient distribution system was a problem because time spent in the system for a late arriving patient is dependent on the time in the system of an eariler arriving patient. To correct for this autocorrelation, replications were used to help reduce the variance. Common random number streams (CRNS) were used on each policy (factor design) for each replication. Thus, for each replication the estimates of the mean are correlated. Correlated sampling was used to induce a positive correlation between the estimates of the mean for each replication, and to achieve a variance reduction in the point estimate of the mean difference between the systems.

This was accomplished by synchronizing the random number seeds across the different systems so that a random number used for a particular purpose in one system is used for the same purpose in all other systems. It also guarantees each system faces identical workloads when the parameters are the same.

Antithetic variates (ATVR) can also be used for each policy separately to induce negative correlation. Pairs of runs of each system are made. Using the average of the two complimentary observations in each pair as a data point for analysis, it can be determined if this average would be a closer estimate of the true mean with a smaller variance than using CRNS.

Law and Kelton (Simulation Modeling and Analysis) warned against mixing CRNS and ATVR when comparing alternative systems because certain "cross covariances" might actually increase the variance. (21) The F test can be used to see if there is a statistical difference in the variance of the two reduction techniques for each system.

F test for equality of variances (95%)

$$H_o : var_1 = var_2$$

$$H_1 : var_1 \neq var_2$$

F policy i = larger of CRNS or ATVR / smaller of CRNS or ATVR

If F calculated is greater than F table for a policy rejection that the variances are equal can be concluded. To avoid mixing techniques while comparing alternative systems, and because time was a factor in obtaining sufficient computer runs for ATVR, the possible increase in accuracy was not deemed to be in the best interest of this study. Thus, ATVR techniques were not used in this study.

Sample Size, Reliability, and Stationarity Consideration

The measure of merit used to evaluate the patient distribution system was the mean total time a patient spent in the system. The system was to be evaluated from the beginning to the end of a relatively short conflict. It

was important to analyze what went on at the start and finish. Thus, the system was a terminating or transient system. The duration of each run was based on the length of war selected. For this study a 60 day war was assumed. Each simulation replication was run for a simulated time interval--0 to 1440 hours.

The simulation was repeated a total of n = 5 times; each run using a different random number seed and independent initial conditions. This includes the case, such as the distribution model, when all runs have identical initial conditions. Because each replication is different, the sample means are statistically independent and thus are not correlated. Each sample mean is statistically independent and identically distributed and are unbiased estimators of the population mean. Thus, classical statistical analysis was used to construct confidence intervals. For constructing a confidence interval, a fixed number of replications should be made (at least two is suggested). If the estimates of the sample mean are assumed to be normal random variables in addition to being independent and identically distributed then a confidence interval (CI) for the population mean is given by:

$$X(n) \pm t_{n-1,1-\alpha/2} \quad S^2(n)/n$$

However, enough replications had to be accomplished to obtain a CI with a specified precision. The actual CI half-length is the absolute precision of the CI. Under the

assumption that the estimate of the population variance, $S^2(n)$, will not appreciably change as the number of replications increased this relation was used:

$$n^*(b) = \min \{i \geq n : t_{i-1,1-\alpha/2} \quad S^2(n)/i \leq B \}$$

as an approximate expression for the total number of replications, $n^*(B)$, required to reduce the absolute precision of the CI to a desired value B (where $B > 0$). Twenty minutes was selected as the difference necessary to discriminate between two competing systems. In the defined system, for an absolute precision of .28 hours (17 minutes), at least five replications for each system were required. Thus, five replications were accomplished to estimate the true average patient time in the system to within .28 hours (17 minutes) with 95 percent confidence. (10:291)

Another measure of precision was relative precision or the ratio of the CI to the magnitude of the point estimator. Again, assuming the population estimates of both mean and variance will not change appreciably as the number of replications increases, the total number of replications can be approximated, $n^*(v)$, required to reduce the relative precision of the CI to a desired value v ($0 < v < 1$) by (10:291):

$$n^*(v) = \min \{ i \pm n : [t_{i-1,1-\alpha/2} \quad S^2(n)/i] / X(n) \leq v \}$$

From the analysis, it was concluded that with five or more total replications estimates of the mean time of patients in the system which differs from the mean value by no more than 1.0 percent of the mean value with 95 percent confidence could be accomplished. This held for all systems.

Although these methods are used for single systems, they form the basis for the paired - t confidence interval in analyzing alternative systems. Thus, these confidence interval procedures can be applied to alternative systems as well. (21:320)

Summary

This chapter has examined the process of data collection and analysis of the data for input parameters in the system. The actual data used for arrival of patients had to be selected so that the system would not "blow-up". However, not much actual data was available for the number of patients arriving. For these reasons, the distribution selected for the number of patients arriving was triangular. The data for available beds in the system was selected from daily bed statistics. The number of beds for the model was selected as the number of beds available at day 30 of the war.

Verification and validation of the model was accomplished throughout the process to ensure that the final model fit the overall systems definition. On initial pilot

runs, it was noted that category three patients had a time in system a magnitude greater than the other categories of patients. Because of this, 14% of the category four patients beds were changed to categroy three beds. This change made policy analysis more meaningful.

After correcting the intial runs, pilot runs were accomplished using common random number streams. Initial calculations showed that five replications were required to have an absolute precision of .28 hours (95% confidence) when comparing different systems.

IV. Experimentation

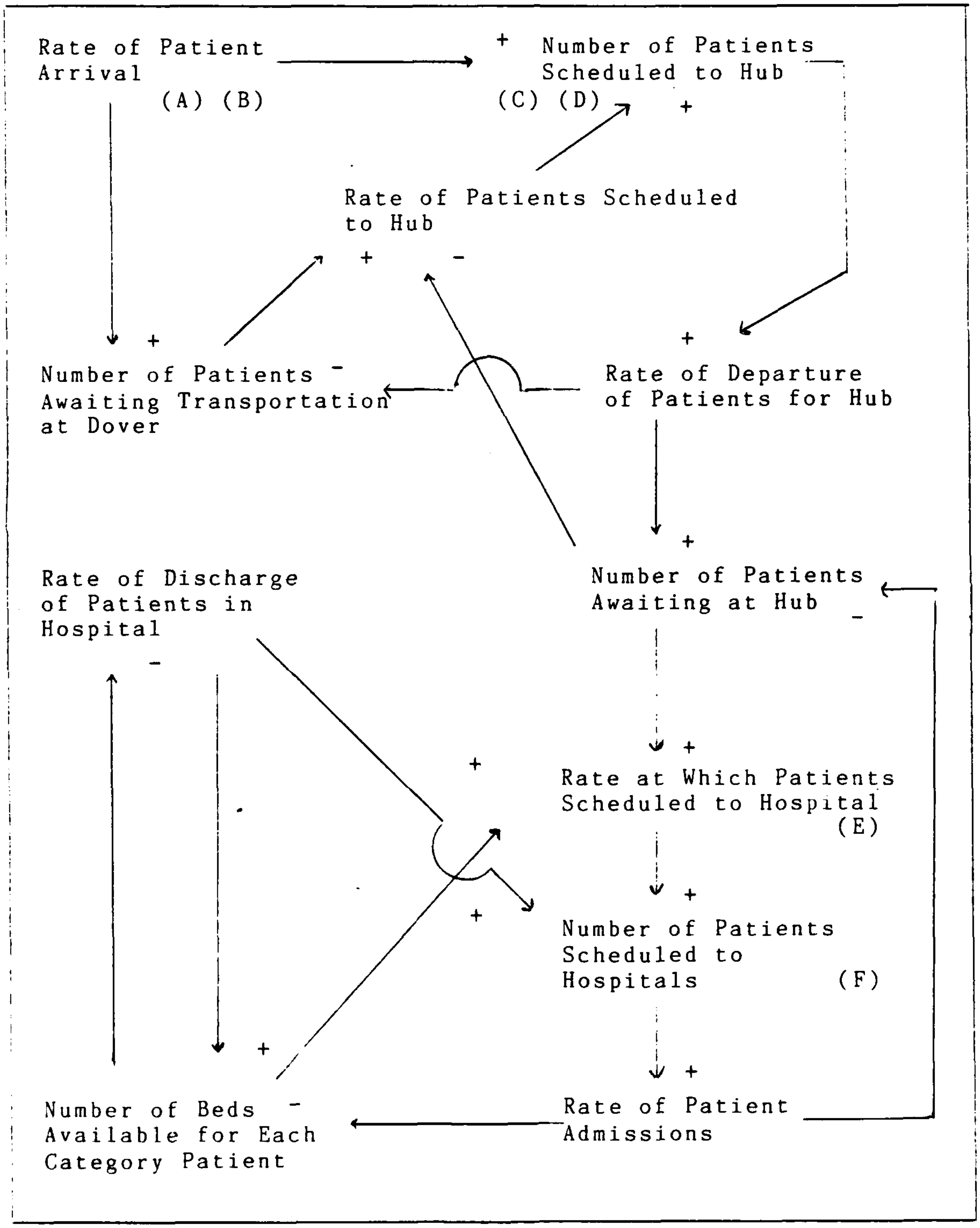
Factors

The development of the structural model was accomplished by defining system relationships through the use of the causal diagram. The causal diagram (Figure 6) was used as an aid for determining all the important variables that are expected to affect the patients time in system.

With reference to the causal diagram, the patients arriving into Dover starts the distribution process. With estimates from LtCol McLain, at Headquarters MAC, it was decided to exercise this arrival rate by: 1) varying the number of patients on the arriving aircraft and, 2) varying the actual arrival rate of the patients. The number of patients arriving, factor A, was set at two levels. The low number of patients arriving was set as a triangular distribution with a range of 160 to 200 patients and a mean of 175. This value was selected as a representative number of patients during the initial stages of the conflict. Estimates of patient arrivals varied any where between 1000 to 2000 patient arrivals per day. (25) The triangular distribution with a mean of 175 patients represents the low value of 1070 patients a day. The high value of factor A was set as a triangular distribution with a range of 160 to 200 patients with a mean of 190. The mean value of 190 patients represents an arrival of 1140 patients per day.

FIGURE 6

Causal Diagram



This number was selected as the high number of arrivals because it provided a patient saturation level high enough to ensure that all three regions are exercised. However, the level is low enough so that the system is not oversaturated.

Factor B was selected to be the arrival rate of the patients into Dover, AFB. The low level of arrival, one load every six hours, represents an arrival rate typical of the initial days of the war. Initially, many casualties will be absorbed into European hospitals. This arrival rate was estimated because no actual data is available. The high level of factor B was set so that one load would arrive at Dover every four hours. Once again, this level was estimated.

The combination of the number of patients arriving and the inter-arrival time of the patients is the determining factor in the number of patients that require beds. The number of beds in the system is constant at 74,725. The system is capable of absorbing this number of patients given that the transportation system is sufficiently large to handle the demand placed on it.

Both factors C and D deal with the CRAF aircraft. The CRAF are everyone's buffer when it comes to war planning. The number of CRAF that would be available in a European war for such an air evacuation is debatable. Even if the CRAF are planned on being used in such a manner, there is no

guarantee all planes would be available. For these reasons five aircraft were selected, for factor C, as the minimum number to operate the system. Without at least five aircraft the system would not function because of the length of the legs to the west coast. The high level of factor C was selected as ten aircraft, which is a more idealistic number of planes.

Factor D represents the capacity of the CRAF. Once again, there are no hard numbers for most CRAF aircraft because there are no current plans to use the planes in an air evacuation role. The DC-8 has a capacity of 219 ambulatory patients; however, during war there are going to be many litter patients. An assumption was made that a 50 percent reduction in carrying capacity would be realized when converting the CRAF to carry litter patients as well. The low level of factor D was set at 100 patients to represent the DC-8 and similar size aircraft. The high level of factor D was set at 175 to represent a DC-10 aircraft. Normally, the DC-10 can carry 315 ambulatory patients. The 50% reduction of carrying capacity represents a conservative estimate of capability. The C-141 aircraft can normally carry 103 litter patients; however, the patient planning factor is 65 patients. This represents a reduction of 37%.

The policy decision of scheduling the CRAF was approximated using factor E. The policy of flying a CRAF

aircraft upon the arrival of the patients was modeled by having the schedule routine attempt to schedule aircraft every hour. The attempt to schedule once an hour represents the high level of factor E. The low level for factor E was set for scheduling aircraft every four hours. This level represents the scheduler attempting to fill the aircraft to a higher patient density before allowing the mission to depart.

The sixth important factor was the number of C-9 aircraft. There are only 11 Air Force C-9 aircraft currently based in the United States. The low level of factor F was set at 10 C-9s per hub. The high level of factor F was set at 15 aircraft per hub. The 15 aircraft represent a possible augmentation of the CONUS C-9 fleet with aircraft from the Pacific or use of similar size commercial aircraft converted for the war effort. It is felt that the number of C-9s and where they are located at different points in the war will be a critical factor in distributing the patients in a timely manner.

The levels of the factors selected were in some cases assumed and in others supported by actual data. However, we felt it important to exercise the model using realistic estimates to see what factors are important. On the surface they all seem to be important ones. The factors, listed below in Table VI served as the basis in the initial experimental design.

TABLE VI

Initial Factors

	FACTOR	LOW	HIGH
A	# PATIENTS ARRIVING	tri(160,175,200)	tri(160,190,200)
B	ARRIVAL RATE	1 per 6 hrs	1 per 4 hrs
C	NUMBER OF CRAF	5	10
D	CAPACITY OF CRAF	100	175
E	SCHEDULE OF CRAF	1 per 4 hrs	1 per hr
F	# C-9 AIRCRAFT	10	15

Design of Analysis

The analysis accomplished next sought to study the effects of the six factors identified. In general, factorial designs are the most efficient manner to accomplish this. In the factorial design, each complete replication of the experiment investigates the possible combinations of the factors at their two levels. (26:189) Factorial designs are more efficient than varying one factor at a time and are necessary when interactions are present. By accomplishing the factorial design it was hoped that important factors and levels of these factors could be identified so that the hub patient distribution system could be analyized in detail.

Screening Design

With these six factors, a complete replicate of the 2^6 design would have required 320 runs of the model. With computer time limited, a 1/4 Fractional Factorial Design was selected or a 1/4 2^{6-2} design. This enabled analysis with significantly fewer runs. The specific resolution used was a resolution four design. This design was structured such that any main factor was not aliased with any other main effect or two factor interaction. However, two factor interactions were aliased with each other. (26:329) The total design is a 2^{6-2} resolution 4 design or a 2^{6-2}_{IV} design. In choosing the 2^{6-2}_{IV} design an assumption was made that the effects of third and higher order interactions were negligible. In addition it was assumed that the population was normally distributed with homogeneity of variance and additivity of effects. These assumptions are necessary ones in order for fractional factorial designs to be valid.

The factors considered in this model are all quantitative factors. The two levels selected represent differing levels of reality depending on the factor. The factors are best estimates of levels that will be seen in a European scenario war without getting into classified data.

Experiments Accomplished

A 2^{6-2}_{IV} design was accomplished. The design generators used were I = ABCE and I = BCDF. These design

Further insight can be gained from the demand for C-9s over time. Figure 7 shows the trend of demand for C-9s over the course of the 60 day war. Peak demand periods occur at times when patients are being distributed into all three regions simultaneously. Perhaps during these periods alternative sources of aeromedical evacuation aircraft may be procured, rather than maintaining a larger fleet for wartime readiness.

Based on arrival rates, the distribution system was qualitatively assessed using C-9 demand per region, bed data and patient characteristics. The CONUS distribution system can be seen to go through four phases during the course of a 60 day war. In the first two weeks of the war, Region 1 can accommodate the influx of patients of all categories. Starting with week three, patient categories begin to fill up in Region 1--forcing the CRAF to transport patients to Region 2 for beds. Category four patients admitted in week one also begin to discharge--opening up more beds in Region 1. In week four category five patients also begin discharging. This second phase lasts for about three weeks. In week six of the war phase three begins. Some patient categories are filled up in Region 1 and Region 2 which forces the CRAF to fly to Region 3 for available beds as well as Region 2. By week seven all five categories of patients admitted during the first week of the war are being

instead of every hour. Thus, if patients had beds in the closest region but could not be airlifted with the available C-9s at that time, they would have to wait four hours before they could be scheduled again (even if a plane was due back before then). This would allow time for another load of patients to arrive into the CONUS and enable the scheduler to fill up more planes to capacity before sending out a plane less than full. The results are in Table XI.

TABLE XI

System Performance With Constrained Scheduling

Avg Time in System	Max Time in System	Max C-9s Allowed Per Region	Max C-9s used Simultaneously
3.56	28.2	Unlimited	16
3.98	84.5	7	16

This policy does not take advantage of the quick turn-around times the C-9s have due to the route structure. More planes are needed at the periods when new patients arrive in the CONUS because of the queued-up patients. Scheduling every hour requires less planes at certain periods of the war; however, you will be flying more sorties with those planes. Because most of the hospitals in a region are within four hours of the HUB, these planes will have enough time to deliver patients and return to the HUB for more arrivals.

the HUBs. To simulate this, the maximum number of C-9s that could be placed at the HUBs for the duration of the war was limited. The number of C-9s ranged from six to twelve maximum per region, and the total number of C-9s used simultaneously in all three regions throughout the course of the 60 day war was monitored. The results are in Table X.

TABLE X

System Performance With Aircraft Constraints

Avg Time in System	Max Time in System	Max C-9s Allowed Per Region	Max C-9s used Simultaneously
3.31	24.8	Unlimited	17
3.39	25.9	10	$14 \leq C\text{-}9 \leq 17$
3.45	25.9	9	$14 \leq C\text{-}9 \leq 17$
3.49	25.9	8	$14 \leq C\text{-}9 \leq 17$
3.61	31.0	7	14
5.67	69.5	6	18

There was no statistical difference in average time in the system when limiting the C-9s to seven, eight or nine per region. The total number used simultaneously was approximately 14. Although this represents a decrease in total aircraft, patient backlogs increased, as well as maximum times in the system.

The next analysis examined how much the aircraft requirements would change if the scheduler attempted to fill every aircraft--even at the expense of delaying some patients until others arrived to fill the aircraft. This was simulated by scheduling aircraft every four hours

First, unlimited C-9s were assumed for each region and the system was tested based on the scheduling policy (schedule patient transportation every hour, load planes to capacity if possible, limit crews to five sorties or 16 hour days) and using the estimated CRAF aircraft requirement. Next, using the maximum number number of C-9s used for each region (12), the system was again tested. However, this time the number of C-9s used concurrently in each region was monitored over the course of the war. It was found that most C-9s used simultaneously in all regions was approximately 17 (see Table IX for results). Observing the transition periods, it appears there is sufficient time to allocate the C-9s in order to schedule all 17 C-9s at once. Implied in this approach is that the scheduler is optimizing the allocation of C-9s to the three HUBs based on demand.

TABLE IX

System Performance

Avg Time in System	Max Time in System	Max C-9s used Simultaneously
3.31	24.8	17

The next question addressed how many C-9 aircraft are required if the scheduler is not quite as efficient. That is, the scheduler could not foresee the demand for C-9s in each region accurately enough to pre-position the C-9s at

the method of loading the aircraft with multiple patient categories for multiple destinations, and 4) the method of scheduling the aircraft. The task is further complicated in this system by: 1) the discharge of patients throughout the system which continually creates more destinations and 2) this system has three pick-up points (HUBs) from which the C-9s can receive their patient loads. Therefore, standard transportation or linear programming algorithms could not be utilized to solve this problem.

In developing this system, it is also assumed that an efficient master scheduler (command center) would allocate C-9s to the HUBs as they were needed. This need would vary over time based on patient arrivals into the HUBs, discharge of patients within the regions, available beds in each region, and CRAF capabilities. Prior to developing this model, it was not known how these interactions would dictate C-9 requirements in each region over the course of the war. Thus, at this point, an algorithm to optimally shift the C-9s from region to region as demand dictated was not possible. A scheduling algorithm in itself is a major research effort. The capability for a computer model to forecast demand within a region, trade-off levels of C-9s in a region for time saved, and schedule the planes to meet that demand is extremely complicated. However, this model did provide enough information upon which to make an estimate. The following procedure was used to estimate the required number of C-9s.

and number of aircraft (5 and 10) fell in the region of the experiment above where no strong conculsions between the systems can be made. With this information, it is evident that at least four aircraft would be required in the patient distribution system, with the measure of merit being a patients time in system. Three or less aircraft had an average and maximum patient time in system two or three times greater depending on aircraft capacity. In addition, the statistical tests did not show that a plane with a capacity of 250 patients provided a decrease in the average patients time in the system. For these reasons further experimentation was accomplished with a fleet of four aircraft having a capacity of 175 patients (DC-10). This is not to say that using a larger aircraft or more than four aircraft would not produce a shorter time in system. The data shows that a shorter time in system can be obtained; however, the use of more or larger aircraft would have to be traded off in cost versus increase in effectiveness.

Determination of C-9 Requirements

After estimating the number and capacity of CRAF aircraft required, the estimate of the number of C-9s required for this patient distribution system was refined. The difficulty of this task is hinged on the elements which encompass any scheduling transportation problem: 1) the turn around time to the destination and return to the pick up point, 2) the quantity of patients per arrival period, 3)

The process involves finding confidence intervals of the difference between the two policies being studied. Any 95% confidence interval that lies totally to the left or right of zero implies strong evidence that the one policy is better than another policies mean time in system.

The number of aircraft was initially held constant across each of the three capacities of aircraft. The results indicate that if only two CRAF aircraft are used in the system then the mean time in system is different for each of the three capacaties. There is strong evidence that policy three is less than policy two which is less than policy one. In accomplishing this same calculation for four to ten aircraft across the three capacities shows that there is a lack of evidence that any one policy is better than any other. The final step of the policy analysis was to repeat the procedure for each capacity of aircraft across all numbers of aircraft. At all CRAF capacities with four to ten aircraft there was no strong evidence to conclude that any policy was better than any other. However, in comparing the policy of two aircraft, to any other number of aircraft, resulted in strong evidence that two aircraft system was inferior.

The results obtained above demonstrated why the capacity and number of CRAF aircraft in the initial experimental design were not significant. This occured because the levels selected for both capacity (100 and 175)

The design of the experiment explained above required 75 runs of the model. The results of the mean time in system for the five replications accomplished are in Table VII.

TABLE VII

Time in System for Different Number of CRAF and Capacities

# AIRCRAFT	POLICY 1 CRAF 100	POLICY 2 CRAF 175	POLICY 3 CRAF 250
2	11.70	8.22	7.06
4	3.63	3.56	3.56
6	3.39	3.40	3.40
8	3.30	3.30	3.30
10	3.30	3.30	3.30

The confidence intervals for the different policies were compared between the different systems. This process helped to answer two questions: 1) How large the mean difference, and how accurate is the estimate of the mean difference? 2) Is there a significant difference between the two systems? The actual calculations involved in comparing two alternative systems is listed below.

$$R = \text{NUMBER OF REPLICATIONS} = 5$$

$$Dr = \text{DIFFERENCE BETWEEN TWO POLICIES}$$

$$\bar{D} = 1/R = .2$$

$$S^2_D = 1/R-1\ (Dr - \bar{D})$$

$$s.e.\ (\bar{D}) = S_D/R$$

$$d.f = R - 1 = 4$$

arriving was not significant in the initial screening design, the high level provided an increased average time in system. The interarrival time of the patients was set at one arrival every four hours. The schedule routine was also set at its worst case level or at one attempt to schedule aircraft every four hours. Finally, the number of C-9 aircraft was established at the low level of 10 aircraft.

The model was then run with differing capacities of CRAF versus the number of CRAF available. For this analysis the number of CRAF was varied from two to ten aircraft, steping by two aircraft. The capacity of the aircraft was established at levels of 100, 175 and 250 patients. The capacity low level of 100 patients represents the number of patients that a DC-8 aircraft could carry with the assumed 50% reduction in normal capacity. It could also be representative of the C-141 aircraft which carries a similar number of patients. The middle level for capacity of 175 patients represents an aircraft with the capacity of the DC-10 aircraft. Finally, the high number of patients was established at 250. This capacity represents a Boeing-747 aircraft with a reduction in capablility. Once again remember that these aircraft capacity levels are hypothesized.

The fact that the number of CRAF (C) was only slightly significant revealed that the levels selected were not highly significant factors when determing a patients time in the system. The capacity of the CRAF (D) and the number of C-9 aircraft (F) had to also be established at more appropriate levels. These three factors represent the factors under control of MAC; therfore critical levels of these factors had to be determined.

Sensitivity Analysis

With the results of the initial screening design available, some more thought had to be given to the levels selected for key factors. The goal of the experimentation was to gain insight on factors under the control of MAC. Therefore, the number of CRAF and the capacity of the CRAF were factors that seemed important in the patient distribution system. However, the initial and subsequent screening design results showed the levels selected were not signicantly different with respect to the mean time in system. With some consultation, it was decided to find the important levels of number of the CRAF aircraft and their capacity before conducting any further experimentation.

The process of finding the important levels of the number and capacity of the CRAF aircraft was accomplished on a worst case basis. The levels of the number of patients arriving was established at the high level of triangular (160,190,200). Although the number of patients

the number of patients waiting. The significance of the A x B interaction also makes sense with the above logic.

Factor (E), the frequency of scheduling aircraft, was highly significant and the causal diagram can explain the system response. As the rate of departure is varied from its low rate of one attempt to schedule every four hours to the high level of one attempt per hour, the rate at which patients are scheduled to the hospitals changes similarly. When the rate of scheduling is set low, the number of patients scheduled to hospitals decrease and the rate of patient admissions decrease. This decrease in patient admissions results in an increase in the number of patients awaiting transportation at the hub. The opposite occurs when the schedule rate is set at the high level.

All factors identified as significant appear to be reasonable in what would take place in reality. The number of patients arriving (A) and the arrival rate of patients (B) determine how many patients are in the distribution system. As the number of patients increases the average time in the system increases. Factor (E), the frequency of scheduling aircraft also makes sense. The time a patient spends in the distribution system is controlled by the scheduler. An inefficient scheduler would prolong the time a patient spends in the system while the efficient scheduler would tend to minimize the time.

factors. With the generators being I = ABCE and I = BCDF the A x B interaction has C x E aliased with it. That is the effect of A x B and C x E are confounded together. The A x C interaction is confounded with the B x E interaction. Therfore, any change to a patients time in system, because of these significant two-way way interactions, may result from one or both of the confounded pairs.

<u>Explaination of Screening Design Results</u>

The important factors identified in the screening design can be explained with reference to the causal diagram (Figure 6).

Factors (A) and (B) determine the rate of arrival of the patients into Dover AFB. As either Factor (A) or (B) is increased the number of patients awaiting transportation at Dover increases as well as the number of patients scheduled to the hubs. However, the number of patients scheduled to the hubs is constrained by the number of CRAF aircraft, factor (C). Within these constraints more patients are scheduled on missions and the rate of departure of patients for the hubs increase; however, the number of patients scheduled is not enough to keep up with the patients awaiting transportation. A queue of patients forms at Dover and the average patient time in the distribution system increases. Factors (A) and (B) are both significant because as they change from low to high levels the number of patients scheduled to the hubs cannot meet the demands of

With the design matrix developed, the 16 runs were made using synchronized common number streams. Five replications of each run were accomplished in order to achieve the desired confidence levels based on the initial pilot runs. The data collected from each replication was the patients mean time in system for the 60 day war, our MOE. The data was then analysed using a regression package. The results are listed in appendix A and will be discussed shortly.

Expectations and Limitations of the Screening Design

The 2^{6-2}_{IV} design helped provide insight into the important factors in the simulation. There are drawbacks to this design. The assumption of negligible higher order interaction and equality of variances being the two major ones. The results of the 2^{6-2}_{IV} design matrix were analyzed. The results show that the following factors were significant with 95 percent confidence: 1) the number of patients arriving (A), 2) the arrival rate of the patients (B), and 3) how often the schedule routine is accomplished (E). The number of CRAF aircraft (C) was only significant with 95 percent confidence. Two factors, the capactiy of the CRAF and the number of C-9s were not significant in the screening design. The only significant factors involving higher order interactions was the A x B and A x C effects. Both of these factors are highly significant.

In the fractional factorial design selected, the generators determine which factors are aliased with other

generators allowed a method to determine which three way and higher interactions were aliased with the six main effects. With the prior assumption that the higher order interactions were negligible, clear cut estimates of the main effects should be possible. The design matrix was generated next to determine the types of computer runs necessary for the design. As the matrix in Table VII illustrates, 16 runs were required to satisfy the experimental design matrix. The left hand column represents the 16 runs accomplished. The columns labeled A thru F represent the six factors listed in table VI and the corresponding levels of these factors in each of the runs. The minus one (-1) represents the low level of the factor and the plus one (+1) represents the high level.

TABLE VII

Initial Screening Design Matrix

		A	B	C	D							E			F	
Run 1	1	-1	-1	-1	-1	1	1	1	1	1	1	-1	-1	-1	-1	1
Run 2	1	1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	-1	-1
Run 3	1	-1	1	-1	-1	-1	1	1	-1	-1	1	1	1	-1	1	-1
Run 4	1	-1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	1	-1
Run 5	1	-1	-1	-1	1	1	1	-1	1	-1	-1	-1	1	1	1	-1
Run 6	1	1	1	-1	-1	1	-1	-1	-1	-1	1	-1	-1	1	1	1
Run 7	1	1	-1	1	-1	-1	1	-1	-1	1	-1	-1	1	-1	1	1
Run 8	1	1	-1	-1	1	-1	-1	1	1	-1	-1	1	-1	-1	1	1
Run 9	1	-1	1	1	-1	-1	-1	1	1	-1	-1	-1	1	1	-1	1
Run 10	1	-1	1	-1	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1
Run 11	1	-1	-1	1	1	1	-1	-1	-1	-1	1	1	1	-1	-1	1
Run 12	1	1	1	1	-1	1	1	-1	1	-1	-1	1	-1	-1	-1	-1
Run 13	1	1	1	-1	1	1	-1	1	-1	1	-1	-1	1	-1	-1	-1
Run 14	1	1	-1	1	1	-1	1	1	-1	-1	1	-1	-1	1	-1	-1
Run 15	1	-1	1	1	1	-1	-1	-1	1	1	1	-1	-1	-1	1	-1
Run 16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

C-9 USAGE TREND CHART
(Per 24 hour period)

Maximum C-9s used in all three regions (hatched)
versus
Maximum C-9s used simultaneously in all three regions (solid)

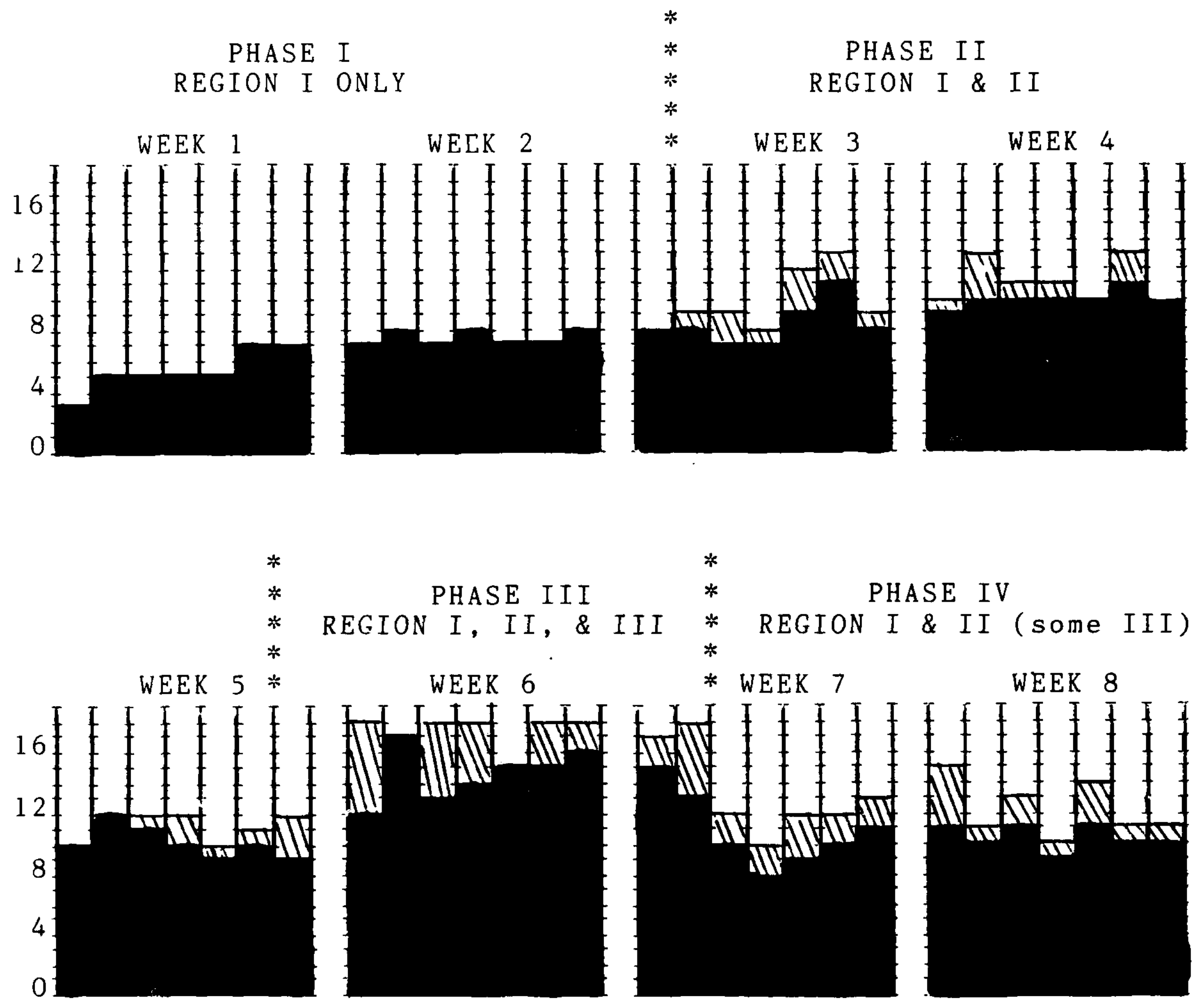


Figure 7

discharged allowing Region 1 and Region 2 to absorb most of the influx of patients in this last phase of the 60 day war.

Further runs were accomplished treating category three and category four patients alike. There was no marked difference in C-9 demand over the course of the war with the exception of a slight decrease in demand for C-9s in Region 3. Because category three beds are no longer the limiting factor (category three patients can fill category four beds), category three patients would no longer back log and the total capacity of the system is increased substantially. Test runs with approximately 1500 patients arriving per day (90000 for the 60 day war) yielded an average time in the system of 3.85 hours without excessive queueing. However, this arrival rate required at least 21 C-9 aircraft and 5 CRAF aircraft with a capacity of 175 patients.

Summary

Six factors were identified as important ones for the patient distribution system: 1) The number of patients arriving, 2) The interarrival time of the patients, 3) The number of CRAF aircraft, 4) The capacity of the CRAF, 5) The scheduling of the aircraft and 6) The number of C-9 aircraft. These factors were set at expected or theorized high and low levels. An initial screening design revealed that factors of interest to the Military Airlift Command, the number and capacity of CRAF and number of C-9 aircraft,

were not significant at the levels selected. A subsequent screening design verified the results.

Initial analysis involved a worst case scenario attempting to find the optimal number of CRAF aircraft and their capacities. With 75 computer runs using different capacities and numbers of CRAF it was determined that four aircraft with a capacity of 175 patients would be the best aircraft for the system under the given conditions. Data runs were then accomplished to find the minimum number of C-9 aircraft that would be needed to keep the patients time in system at the same levels. Based on this analysis, it was determined that the eleven Air Force C-9 aircraft based in the CONUS are not sufficient to operate the system. In order for the proposed system to work, at least 14-17 C-9 aircraft are required to handle an estimated arrival rate of 1000 patients per day.

V. Conclusions and Recommendations for Further Study

Conclusions

This study tested the feasibility of a CONUS casualty distribution system using dedicated CRAF airlift in a HUB-and-spoke-type operation. Although this system is not optimal, it does provide a close approximation to the manner in which the actual system might operate. Because the number of beds of some category patients did not accommodate the expected demand, the scenario constrained demand on the system so as not to overflow any single category of hospital bed. None-the-less, approximately 60,000 patients were distributed during the course of the war.

The concept of utilizing CRAF aircraft, in conjunction with C-9 aircraft, in a patient hub distribution system appears to be a viable option. The current system utilizes C-141 aircraft returning from Europe on primary resupply missions to deliver the patients to the resupply base. From this base C-9 aircraft are then used to fly patients to their final hospitals. The hub system attempts to deliver the patients in a more effective manner while using the C-9 aircraft more efficiently.

To provide the necessary analysis, a background study of the current system was accomplished in order to identify key components in a patient distribution system. Using this information a simulation of the proposed distribution system was constructed. Actual data for some of the important

factors, such as, CRAF capacity and patient arrival rates was not available. In these cases, best estimates were used. The model developed simulated a 60 day war with over 1000 casualties arriving daily. Verification and validation of the model were accomplished and the results of the model appeared to be reasonable.

The focus of the analysis centered on those variables that were under control of the Military Airlift Command. Namely the number of CRAF aircraft necessary to operate the system, the capacity of these CRAF aircraft and the number of C-9 aircraft required. The system response was measured by the average patient time in the system. A secondary measures of effectiveness was the maximum time any one patient spent in the system.

The design of the experiment selected assumed two factor interactions as the highest interactions to be considered. The design required 80 computer runs of the simulation. The results showed that the factors of interest, the number of CRAF, their capacity, and the number of C-9 aircraft was not significant. The reason for this was that the levels selected for these factors were initially set too high. That is, there was not a significant difference in a patients time in system between the low level and the high level selected. Therefore, further computer runs were accomplished to identify the optimum number of CRAF aircraft and the capacity of these

aircraft. The results of this analysis showed that four aircraft with a capacity of 175 patients was required.

With the number and capacity of CRAF aircraft identified, the focus of the experimentation shifted to finding the number of C-9 aircraft required to operate the system effectively. This analysis was accomplished in three phases. The first phase consisted of a hub system with an unlimited number of C-9 aircraft. Although not a reasonable solution, the number of C-9 aircraft used in this system provided an estimate of how an efficient scheduler might utilize the aircraft. The number of aircraft utilized at any one time was 17 aircraft. The average patient spent 3.31 hours in the system.

The second phase of C-9 analysis involved seeing how the patients time in system changed as the number of C-9 aircraft allowed in any region was constrained. These results show that at least seven aircraft per region are required to keep the patients time in the system statistically the same as the unlimited C-9 system without causing excessive patient queueing. The final phase of C-9 analysis involved allowing patients to queue at a hub in an attempt to fill the C-9s to capacity. These results show that the fewer aircraft can be utilized (16 maximum); however, the maximum time any one patient spends in the system increases significantly.

Because the number of C-9s currently based in the CONUS do not adequately support the distribution system as presented in this study, it is recommended that the Military Airlift Command seek alternative ways to procure the needed capacity. For example, utilize Navy C-9s, CRAF, or contract airlift in the role of the C-9.

The results of the experimentation showed that there are a number of factors that affect the delivery of patients and more importantly the patients time in system. All trends were consistent with the hypothesized relationships developed in the causal diagram. The model provides an important aid in analyzing the impact of policy changes in the defined system.

The model, as developed, can accommodate a wide range of scenarios. By changing the number of patients and interarrival times of the patients, any level of conflict can be analyzed. In addition, analysis of capacity and number of CRAF aircraft can be accomplished to see system results. More effort would be required to change the number of hubs in the system. This would require new calculations on the hub locations using Weber theory. Bed data would also have to be changed to the new regions developed.

Recommendations for Future Study

Patient Category Characteristics As They Affect Scheduling. Patients are expected to stay in the hospitals anywhere from two to more than eight weeks depending on

their category. Therefore, some categories of beds will turn over patients one to four times for a 60 day war (more if the war is longer). Does this rate of turn-over have an effect on where certain patient categories should be scheduled first? For example, would it be more efficient to schedule patients with hospital stays of eight weeks in the farthest region from the CONUS arrival point--leaving more aircraft to fly patients who require shorter lengths of stay closer to the arrival point? Would this type of policy lessen tne conjestion in any of the regions?

An off-shoot of this analysis would be to weight the CMCHS locations according to the bed data along with their distances. Give more weight to beds which are for patients with shorter lengths of stay. Input these weights into the moment-sum algorithm and determine if the calculated HUB locations change. What effect does weighting the hospitals based on bed data have on the distribution system?

Another area of study would examine to what degree patients of one category can fill beds of a different category within certain medical constraints. Since this scenario represents a crisis situation, medical personnel may be forced to cross-match beds and patients. What effect will this have on scheduling patients and aircraft requirements.

Extensions of Current Model. This study assumed all patient arrivals would enter the CONUS in Region 1. Because the northeast bases and airports will be highly conjested during wartime this may not be completely feasible. An extension of this study should be accomplished starting with the loading of patients aboard aircraft in Europe. CRAF aircraft can then fly directly into Region 1 or Region 2 relieving some of the conjestion. What effect will this capability have on total CRAF and C-9 requirements?

Although this study only evaluated a three HUB distribution system, perhaps a different number of HUBs would yield better results. Further research could also be done on scheduling policies within a HUB distribution system. For example, because there are a limited number of C-9s, would a policy of utilizing C-9s in no more than two HUBs at a time more effectively utilize the aircraft?

A broader question is whether HUBs based on central locations is appropriate for the scenario anticipated. Package delivery services use this method because packages come into the HUB from all directions and are delivered out of the HUB in all directions. However, with a European war scenario, casualties will arrive into the CONUS from only one direction and then be distributed to the hospitals throughout the CONUS. Is it possible to take advantage of this directional characteristic in formulating a patient

distribution system to reduce some of the duplication of travel time; or are central HUBs still more efficient?

Finally, more stochastic variance can be introduced into the system. What effects will aircraft reliability, weather, air traffic control sequencing, etc. have on the patient distribution system?

Computerized Scheduling Algorithms. For the anticipated number of casualties arriving into the CONUS each day, it will be virtually impossible for airlift schedulers and medical personnel to optimally load and schedule aircraft with patients. Present methods of scheduling will probably not be able to keep up with the arrival rates of the patients--resulting in mismanagement and inefficient scheduling. Therefore, computerized scheduling algorithms need to be developed to assist the medical and airlift personnel to more effectively and efficiently utilize their aeromedical evacuation resources.

Of course these algorithms can only be developed after a pre-determined wartime patient distribution system is selected. These scheduling algorithms should have the ability to monitor bed data over a period of time (i.e. every 12 hour updates) and for some time in the future. It would also be able to forecast the discharge of patients based on hospital inputs and enter this into the bed data base. As hospitals fill up, the algorithm should be able to anticipate a change in demand for aircraft in certain

regions and alert the scheduler to pre-position these aircraft to another region where the demand will be great.

Closing Thought

Regardless of whether one system is more "optimal" than another-it has become apparent that any patient distribution system is better than no system at all. That is, an optimal system would be nice to achieve, but it is not a necessity. If an intense conventional European war ever becomes a reality, there must be a feasible, preconceived plan of operations to distribute the patients. Otherwise, this nation's casualties will fall victim to chaos and increased suffering. And, who knows what kind of detrimental effect this will have on the war-fighting capability of this nation?

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AD-A156 076 WARTIME CONUS (CONTINENTAL UNITED STATES) CASUALTY DISTRIBUTION SYSTEM SS..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. 2/2

UNCLASSIFIED J P ALFANO ET AL. MAR 85 AFIT/GST/OS/85M-1 F/G 15/5 NL

END

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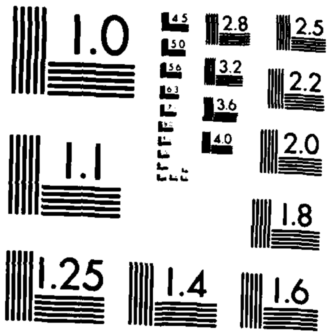

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Patient Aeromedical Evacuation Categories

(1) Medical (MIM).

(2) Psychiatric (OPG).

(3) General Surgery (SGS).

(4) Orthopedic (SOR).

(5) Neurosurgery (SNS).

(6) Oral/Maxillo Facial (SMF).

(7) Urology (SUR).

(8) Opthamology (SOP).

(9) Burns (SBN).

(10) Thoracic Surgery (STH).

(11) Spinal Cord (SCI).

CONUS Casualty Distribution System

Civilian-Military Contingency Hospital System (CMCHS)
Locations - 73 CMCHS

Region 1 : Northeastern & Mid-Atlantic United States
Locations - 14 CMCHS

Region 2 : Central & Southeastern United States
Locations - 40 CMCHS

Region 3 : Western United States
Locations - 19 CMCHS

Total Beds : 74725 [( ) represents 14% adjustment]

Cat I	7145	
Cat II	13270	
Cat III	7735	(12120)
Cat IV	31330	(26945)
Cat V	15245	

Region 1 : Northeastern & Mid-Atlantic United States

Total Beds : 22360

Cat I	1930	
Cat II	4070	
Cat III	1925	(3215)
Cat IV	9200	(7900)
Cat V	5235	

HUB : 1. Dover AFB, Delaware

Spoke 1		Spoke 2	
2.	McGuire	2.	Andrews
3.	Philadelphia	3.	Norfolk
4.	Stewart	4.	Richmond
5.	T. F. Green	5.	Langley
6.	Hanscom	6.	Cherry Point
7.	Pease	7.	Pope
8.	Plattsburg		

Region 2 : Central & Southeastern United States

Total Beds : 33465

Cat I : 3430
Cat II : 5805
Cat III : 3455 (5455)
Cat IV : 14275 (12275)
Cat V : 6500

HUB : 1. Maxwell AFB, Alabama

Spoke 1		Spoke 2		Spoke 3	
2.	Dothan	2.	Ft. Benning	2.	Keesler
3.	Pensacola	3.	Augusta	3.	England
4.	Eglin	4.	Wright	4.	Barksdale
5.	Jacksonville	5.	Beufort	5.	Corpus Christi
6.	Orlando	6.	Charleston	6.	Kelly
7.	Patrick	7.	Shaw	7.	Robert Grey
8.	McDill	8.	Huntsville	8.	Dyess
9.	Homestead	9.	Birmingham	9.	Carswell
		10.	Sheppard		

Spoke 4		Spoke 5	
2.	Memphis	2.	Scott
3.	Ft. Campbell	3.	Kansas City
4.	Standford	4.	Forney
5.	Wright-Patterson	5.	Offutt
6.	Indianapolis	6.	Tinker
7.	Glenview	7.	Lawton
8.	Champaign	8.	Little Rock

Region 3 : Western United States

Total Beds : 18900

Cat I : 1785
Cat II : 3395
Cat III : 2355 (3455)
Cat IV : 7855 (6755)
Cat V : 3510

HUB : 1. March AFB, California

Spoke 1	Spoke 2
2. Vandenberg	2. Long Beach
3. Monterey	3. Miramar
4. Oakland	4. Davis Montham
5. Travis	5. Williams
6. Mather	6. Luke
7. Tacoma	7. El Paso
8. Fairchild	8. Albuquerque
	9. Colorado Springs
	10. Buckley
	11. Ellsworth
	12. Minot

Time in System Resolution 4

Source	SS	df	MS	F*	
Regression	12.05872	15	.8039143	48.09059	p = .0000
Error	.5349333	32	1.671667E-02		
Total	12.59365	47			

R^2 = .9575   Adjusted R^2 = .9376

Effect	Beta	Std Error	t*	p
Mean	2.908959			
A	5.895834E-02	1.866183E-02	3.159301	.0034
B	.3464584	1.866183E-02	18.56508	.0000
C	-.031875	1.866183E-02	-1.708032	.0973
D	4.791667E-03	1.866183E-02	.256763	.7990
AXB	4.145834E-02	1.866183E-02	2.221558	.0335
AXC	.250625	1.866183E-02	13.42982	.0000
AXD	.005625	1.866183E-02	.3014174	.7650
BXC	-3.104167E-02	1.866183E-02	-1.663377	.1060
BXD	4.791667E-03	1.866183E-02	.256763	.7990
CXD	-6.041667E-03	1.866183E-02	-.3237446	.7482
E	-.246875	1.866183E-02	-13.22887	.0000
AXBXD	.005625	1.866183E-02	.3014174	.7650
AXCXD	-6.041667E-03	1.866183E-02	-.3237446	.7482
F	-6.041667E-03	1.866183E-02	-.3237446	.7482
AXBXCXD	-6.041667E-03	1.866183E-02	-.3237446	.7482

Bartlett's test for homogeneity of variance:
Xo^2 = 75.7116   df = 15   p = .0000

```
         |                                          *    *
         |
         |                                            *
         |
         |                                        *
Residual |--**------------------------------***---*--------- Fitted
         |                                   *        *
         |                                            *
         |                                          *    *
         |
```

```
gen,JOE and JOHN,THESIS,01/07/85,5
limits,19,6,3000;
timst,xx(1),NUMBER PAT GENERATED;
timst,xx(2),NUMBER AT MCQUIRE;
timst,xx(4),CRAF COUNTER;
timst,xx(10),WEEKDAY;
network;
       resource/craf(10),16;
       resource/c9dover(20),17;
       resource/c9maxwe(20),18;
       resource/c9march(20),19;
;***********************************************************
;  THIS ROUTINE SERVES AS A DAILY COUNTER, 24 HOURS, FOR
;  UPDATING THE NUMBER OF PATIENTS IN EACH HOSPITAL.  AT
;  THE END OF 7 DAYS, WEEKLY KEEPS ARE DONE MOVING PATIENTS
;  IN THE HOSPITAL ONE WEEK CLOSER TC DISCHARGE
;***********************************************************
cre3   create;
loop   assign,xx(10)=xx(10) + 1;
       act/53,24.0;
ev2    event,2,1;
       act/54,,xx(10) .lt. 7, loop;
       act/55;
       assign, xx(10) = 0;
ev1    event,1,1;
       act/56,,,loop;
       term;
;*********************************************************
;  THIS ROUTINE SERVES AS THE MASTER SCHEDULER.  IT STEPS
;  THROUGH THE REGIONS 1,2 AND 3.
;*********************************************************
cre1   create,1;
       act,.0001;
reg1   assign,atrib(5)=1.0,1;
       act/1;
ev4a   event,4,1;
       act,.0001;
       event,5;
       act,.0001;
       event,7;
       act,.0001;
       goon,1;
       act,,xx(15) .eq. 1.0, reg2;
       term;
reg2   assign,atrib(5)=2.0,1;
       act/2;
ev3a   event,3,1;
       act,.0001;
       event,8;
       act,.0001;
       goon,1;
       act,,xx(15) .eq. 1.0, reg3;
       term;
```

```
reg3    assign,atrib(5)=3.0,1;
        act/3;
ev3b    event,3,1;
        act,.0001;
        event,8;
        term;
;*****************************************************************
;  THIS ROUTINE CONTROLS THE ARRIVAL OF C-141 AIRCRAFT INTO
;  DOVER. THE PATIENTS ARE ASSIGNED THEIR CATEGORY (ATRIB2)
;  AND THEIR LENGTH OF STAY (ATRIB4).  THE PATIENTS ARE
;  THEN ASSIGNED TO QUEUES ACCORDING TO THEIR CATEGORY
;*****************************************************************
cre2    create,4,,1;
ass1    assign,xx(1)= 125;
ass2    assign,xx(2) = 0;
make    assign, xx(2) = xx(2) + 1,2;
        act/4,, xx(2) .lt. xx(1),make;
        act/5,,,mcqu;
        term;
mcqu    goon,1;
        act/6,,.10,cont;
        act/7,,.20,q2;
        act/8,,.19,q3;
        act/9,,.20,q4;
        act/10,,.31,q5;
cont    goon,1;
        act/70,,.4,ass3;
        act/71,,.3,ass4;
        act/72,,.2,ass5;
        act/73,,.1,ass6;
ass3    assign,atrib(4)=8.0;
        act/74,,,q1;
ass4    assign,atrib(4)=5.0;
        act/75,,,q1;
ass5    assign,atrib(4)=6.0;
        act/76,,,q1;
ass6    assign,atrib(4)=3.0;
        act/77,,,q1;
q1      assign,atrib(2) = 1.0,1;
que1    queue(1);
        term;
q2      assign,atrib(2) = 2.0;
        assign,atrib(4) = 7.0;
que2    queue(2);
        term;
q3      assign,atrib(2) = 3.0;
        assign,atrib(4) = 8.0;
que3    queue(3);
        term;
q4      assign,atrib(2) = 4.0;
        assign,atrib(4) = 4.0;
que4    queue(4);
        term;
```

```
q5      assign,atrib(2) = 5.0;
        assign,atrib(4) = 5.0;
que5    queue(5);
        term;
;*************************************************************
;  THIS ROUTINE FLYS THE PATIENTS FROM DOVER TO MAXWELL AND
;  SORTS THE PATIENTS AT MAXWELL BY CATAGORY.
;*************************************************************
e9      enter,9,1;
        act/11,4.0;
        goon,1;
        act/12,,atrib(2) .eq. 1.0,q6;
        act/13,,atrib(2) .eq. 2.0,q7;
        act/14,,atrib(2) .eq. 3.0,q8;
        act/15,,atrib(2) .eq. 4.0,q9;
        act/16,,atrib(2) .eq. 5.0,q10;
q6      queue(6);
        term;
q7      queue(7);
        term;
q8      queue(8);
        term;
q9      queue(9);
        term;
q10     queue(10);
        term;
;*************************************************************
;  THIS ROUTINE ROUTES CRAF AIRCRAFT FROM DOVER TO MAXWELL
;  AND FREES THE CRAF AFTER ITS RETURN FLIGHT TO DOVER.
;*************************************************************
e12     enter,12;
        await(16),craf/1,1;
        act/17,4.0;
        goon,1;
        act/18,.001;
ev4b    event,4,1;
        act,.0001;
        event,5;
        act,.0001;
        goon,1;
        act/19,5.75;
        free,craf/1;
        term;
;*************************************************************
;  THIS ROUTINE FLYS THE PATIENTS FROM DOVER TO MARCH AND
;  SORTS THE PATIENTS AT MARCH BY CATAGORY.
;*************************************************************
e10     enter,10;
        act/21,6.75;
        goon,1;
        act/22,,atrib(2) .eq. 1.0,q11;
        act/23,,atrib(2) .eq. 2.0,q12;
        act/24,,atrib(2) .eq. 3.0,q13;
```

```
        act/25,,atrib(2) .eq. 4.0,q14;
        act/26,,atrib(2) .eq. 5.0,q15;
q11     queue(11);
        term;
q12     queue(12);
        term;
q13     queue(13);
        term;
q14     queue(14);
        term;
q15     queue(15);
        term;
;*********************************************************
;  THIS ROUTINE ROUTES CRAF AIRCRAFT FROM DOVER TO MARCH
;  AND FREES THE CRAF AFTER ITS RETURN FLIGHT TO DOVER.
;*********************************************************
e14     enter,14;
        await(16),craf/1,1;
        act/27,6.75;
        goon,1;
        act/28,.001;
ev4c    event,4,1;
        act,.0001;
        event,5;
        act,.0001;
        goon,1;
        act/29,10.5;
        free,craf/1;
        term;
;**********************************************************
;  THIS ROUTINE SERVES TO SCHEDULE THE C-9 AIRCRAFT FROM
;  DOVER TO DESTINATION HOSPITALS. AFTER OFFLOADING PATIENTS
;  AT FINAL DESTINATION THE AIRCRAFT IS RETURNED AND FREED.
;**********************************************************
e16     enter,16;
awt1    await(17),c9dover/1,1;
ev6a    event,6,1;
        act/41,atrib(6);
        free,c9dover/1;
        term;
;**********************************************************
;  THIS ROUTINE SERVES TO SCHEDULE THE C-9 AIRCRAFT FROM
;  MAXWELL TO DESTINATION HOSPITALS. AFTER OFFLOADING
;  AT FINAL DESTINATION THE AIRCRAFT IS RETURNED AND FREED.
;**********************************************************
e17     enter,17;
awt2    await(18),c9maxwe/1,1;
ev6b    event,6,1;
        act/43,atrib(6);
        free,c9maxwe/1;
        term;
```

```
;************************************************************
;  THIS ROUTINE SERVES TO SCHEDULE THE C-9 AIRCRAFT FROM
;  MARCH TO DESTINATION HOSPITALS.  AFTER OFFLOADING PATIENTS
;  AT FINAL DESTINATION THE AIRCRAFT IS RETURNFD AND FREED.
;***************************************************************
el8     enter,18;
awt3    await(19),c9march/1,1;
ev6c    event,6,1;
        act/45,atrib(6);
        free,c9march/1;
        term;
;************************************************************
;  THIS ROUTINE ASSIGNS THE PATIENTS THEIR FLIGHT TIME
;  ON THE C-9 AND COLLECTS STATISTICS ON THE PATIENTS WHEN
;  THEY ARE OFFLOADED AT THEIR FINAL DESTINATION
;************************************************************
el9     enter,19,1;
        act/47,atrib(3);
colct   colct,int(1), TIME IN SYSTEM,,1;
        act/48,, atrib(2) .eq. 1.0,col1;
        act/49,, atrib(2) .eq. 2.0,col2;
        act/50,, atrib(2) .eq. 3.0,col3;
        act/51,, atrib(2) .eq. 4.0,col4;
        act/52,, atrib(2) .eq. 5.0,col5;
col1    colct,int(1), CATAGORY 1 TIS;
        term;
col2    colct,int(1), CATAGORY 2 TIS;
        term;
col3    colct,int(1), CATAGORY 3 TIS;
        term;
col4    colct,int(1), CATAGORY 4 TIS;
        term;
col5    colct,int(1), CATAGORY 5 TIS;
        term;
;***********************************************************
        end;
init,0,1440;
fin;
```

```
*     1-10-85
      program main
      dimension nset(50000)
      common/scoml/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     1,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
      common qset(50000)
      equivalence(nset(1),qset(1))
      nnset=50000
      ncrdr=5
      nprnt=6
      ntape=7
      open(7,status='scratch')
      call slam
      stop
      end
***********************************************************
      subroutine intlc
      dimension nset(50000)
      common/scoml/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     1,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
      common qset(50000)
      equivalence (nset(1),qset(1))
      common/mycom/ibed(3,40,5,8),avlbed(3,5),crload(3),load(3),
     &              ffload(3),bedavl(3),j(3),dis(9,12,12)
      integer avlbed(3,5),crload(3),load(3),ffload(3),bedavl(3)
      real dis(9,12,12)
************************************************************
*  THIS PROCEDURE ACCESSES A DATA FILE WITH THE COMPUTED    *
*  GREAT CIRCLE DISTANCES BETWEEN HOSPITALS IN EACH SPOKE   *
*  WITHIN EACH REGION.                                      *
************************************************************
      if (nnrun .eq. 1) then
400     format(3x,12(x,f6.1))
        open(1,file="bigmat")
        rewind 1
        do 500 k = 1,9
          do 500 n = 1,12
        read(1,400)(dis(k,n,m),m=1,12)
500     continue
        endfile 1
        close(1)
      endif
*
      do 80 ireg = 1,3
        do 80 ihosp = 1,40
          do 80 icat = 1,5
            do 80 iweek = 2,8
              ibed(ireg,ihosp,icat,iweek)=0
80      continue
      avlbed(1,1)=1930
      avlbed(1,2)=4069
      avlbed(1,3)=1923
      avlbed(1,4)=9202
```

```
      avlbed(1,5)=5235
      avlbed(2,1)=3431
      avlbed(2,2)=5803
      avlbed(2,3)=3455
      avlbed(2,4)=14273
      avlbed(2,5)=6498
      avlbed(3,1)=1785
      avlbed(3,2)=3396
      avlbed(3,3)=2355
      avlbed(3,4)=7856
      avlbed(3,5)=3510
      call event(2)
      return
      end
*********************************************************************
      subroutine event(ix)
      dimension nset(50000)
      common/scoml/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     1,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
      common qset(50000)
      equivalence(nset(1),qset(1))
      common/mycom/ibed(3,40,5,8),avlbed(3,5),crload(3),load(3),
     &              ffload(3),bedavl(3),j(3),dis(9,12,12)
      integer avlbed(3,5),crload(3),load(3),ffload(3),bedavl(3)
      integer catq,ix,count,dischg,capcty
      integer start(3),stop(3),sphosp(9)
      real wkday,flytme,delay,delayt,hpstay,reg
      real flag,rv,dis(9,12,12),iretrn,time,totdel
      equivalence (wkday,xx(10))
      equivalence (flytme,atrib(6))
      equivalence (flag,xx(15))
      equivalence (delay,atrib(3))
      equivalence (hpstay,atrib(4))
      equivalence (reg,atrib(5))
      goto (1,2,3,4,5,6,7,8), ix
****************************************************************
* THIS ROUTINE DOES WEEKLY UPDATES ON BEDS AVAILABLE IN EACH*
*   CATEGORY, AT EACH HOSPITAL, IN EACH REGION                *
****************************************************************
1         do 10 ireg = 1,3
            do 10 ihosp = 1,40
              do 10 icat = 1,5
                do 20 iweek = 3,8
                  ibed(ireg,ihosp,icat,iweek-1)
     &                 = ibed(ireg,ihosp,icat,iweek)
20              continue
                  ibed(ireg,ihosp,icat,8)=0
10         continue
          return
```

VITA

Captain John C. O'Neill was born on 27 July 1954 in Los Angeles, California. Upon graduating from high school in 1972 in West Covina, California, he attended the United States Air Force Academy Prepatory School. In 1977 he received a Bachelor of Science degree in Psychology from the United States Air Force Academy. In the summer of 1977, he attended Undergraduate Pilot Training at Vance Air Force Base in Enid, Oklahoma and received his wings in June of 1978. He was then assigned to the 15th Military Airlift Squadron at Norton Air Force Base, California. He flew as an instructor pilot and flight examiner in the C-141 aircraft until entering the School of Engineering, at the Air Force Institute of Technology, in August 1983.

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VITA

Captain Joseph P. Alfano was born 17 May 1955 in Newark, New Jersey. Upon graduating from Raritan High School in Hazlet, New Jersey in 1973, he attended the United States Air Force Academy from which he received a Bachelor of Science degree in Economics and Management in 1977. Following graduation, he attended Undergraduate Pilot Training at Williams AFB, Arizona and received his wings in October of 1978. He was then assigned to the 6th Military Airlift Squadron at McGuire AFB, New Jersey. There he accumulated over 2000 flying hours as an Instructor Aircraft Commander and as a member of the Military Airlift Command's Prime Nuclear Airlift Force. During this assignment he also served as an assistant to the Chief Pilot for scheduling and training and executive officer to the commanders of the 6th Military Airlift Squadron and 438th Military Airlift Wing. In 1983 Captain Alfano completed Squadron Officer School at Maxwell AFB, Alabama. He then attended the Air Force Institute of Technology, School of Engineering, Wright Patterson AFB, Ohio from which he received a Master of Science degree in Operations Research (Strategic and Tactical Sciences) in March 1985.

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```
      print*,'Enter 1 for same T/O point, 2 for same Dest,'
      print*,' 3 for DEST to T/O, 4 for new T/O and Dest.'
      read*,choice
      if (choice .eq. 1) then
        goto 50
      endif
      if (choice .eq. 2) then
        goto 30
      endif
      if (choice .eq. 3) then
        ta = la
        ma = lm
        tl = ll
        ml = ln
        x = y
        goto 50
      endif
      if (choice .eq. 4) then
        goto 30
      endif
      end
*
      subroutine distan(f1,f2,t1,t2,gc)
      real f1,f2,t1,t2,s1,s2,c1,c2,c3,g1,g2,gc,earthr,dtor
      earthr = 60.0 * (180/3.1415927)
      dtor = .0174533
      s1 = sin(f1 * dtor)
      s2 = sin(t1 * dtor)
      c1 = cos(f1 * dtor)
      c2 = cos(t1 * dtor)
      c3 = cos((t2 * dtor) - (f2 * dtor))
      g1 = s1 * s2 + c1 * c2 * c3
      g2 = acos(g1)
      gc = g2 * earthr
      return
      end
```

```
**********************************************************
*  THIS PROGRAM COMPUTES THE GREAT CIRCLE DISTANCE         *
* BETWEENTWO POINTSBASED ONLATITUDE AND LONGITUDE          *
*  COORDINATES IN DEGREES AND MINUTES.  DISTANCE IS        *
*  COMPUTED IN NAUTICAL MILES.                             *
**********************************************************
        program great circle distance (mac xpsr)
        real ta,ma,tl,ml,ll,ln,fl,f2,tl,t2,la,lm,gc
        integer choice,x,y
30      print*,'Enter Hospital Number'
        read*,x
        print*,'Enter Takeoff Latitude (deg,min)'
        read*,ta,ma
        print*,'Enter Takeoff Longitude (deg,min)'
        read*,tl,ml
        if (choice .eq. 2) then
          goto 63
        endif
50      print*,'Enter Destination Hospital'
        read*,y
        print*,'Enter Destination Latitude (deg,min)'
        read*,la,lm
        print*,'Enter Destination Longitude (deg,min)'
        read*,ll,ln
63      fl = ta + ma/60.0
        f2 = tl + ml/60.0
        tl = la + lm/60.0
        t2 = ll + ln/60.0
        call distan(fl,f2,tl,t2,gc)
        print*,'Takeoff Hospital is       : ',x
        print*,'Takeoff Latitude is       : ',ta, ma
        print*,'Takeoff Longitude is      : ',tl, ml
        print*,'Destination Hospital is   : ',y
        print*,'Destination Latitude is   : ',la,lm
        print*,'Destination Longitude is  : ',ll,ln
        print*
        Print*,'Great Circle Distance between hospitals:',gc
        print*
        choice = 0
```

```
************************************************************
* THIS ROUTINE CHECKS FOR PATIENTS IN THE QUEUE AND IF THERE*
* ARE BEDS AVAILABLE.  IF NO BEDS ARE AVAILABLE THE FLAG IS *
* SET TO ONE ALLOWING PATIENTS TO FLY TO REGION 2           *
************************************************************
7       id1 = 0
        id2 = 0
        id3 = 0
        id4 = 0
        id5 = 0
        ireg = int(reg)
          if (ireg .eq. 1)then
            if (nnq(1) .gt. 0)then
              if ((avlbed(ireg,1) - nnq(1)) .ge. 0)then
                id1 = 0
              else
                id1 = 1
              endif
            endif
            if (nnq(2) .gt. 0)then
              if ((avlbed(ireg,2) - nnq(2)) .ge. 0)then
                id2 = 0
              else
                id2 = 1
              endif
            endif
            if (nnq(3) .gt. 0)then
              if ((avlbed(ireg,3) - nnq(3)) .ge. 0)then
                id3 = 0
              else
                id3 = 1
              endif
            endif
            if (nnq(4) .gt. 0)then
              if ((avlbed(ireg,4) - nnq(4)) .ge. 0)then
                id4 = 0
              else
                id4 = 1
              endif
            endif
            if (nnq(5) .gt. 0)then
              if ((avlbed(ireg,5) - nnq(5)) .ge. 0)then
                id5 = 0
              else
                id5 = 1
              endif
            endif
          endif
          if (ireg .eq. 1 .and. (id1+id2+id3+id4+id5).ge. 1) then
              flag = 1.0
            endif
          return
          end
```

```
          bedavl(ireg)=
     &     ibed(ireg,idest,icat,1)-ibed(ireg,idest,icat,2)-
     &     ibed(ireg,idest,icat,3)-ibed(ireg,idest,icat,4)-
     &     ibed(ireg,idest,icat,5)-ibed(ireg,idest,icat,6)-
     &     ibed(ireg,idest,icat,7)-ibed(ireg,idest,icat,8)
          if (bedavl(ireg) .eq. 0)then
           goto 640
          endif
           if ((bedavl(ireg)+crload(ireg)).gt.capcty)then
             if (crload(ireg) .lt. capcty) then
               load(ireg)=capcty-crload(ireg)
               if (nnq(catq) .lt. load(ireg)) then
                 load(ireg) = nnq(catq)
               endif
             else
               load(ireg) = 0
             endif
           else
             load(ireg)=bedavl(ireg)
             if (nnq(catq) .lt. load(ireg)) then
               load(ireg) = nnq(catq)
             endif
           endif
           if (ireg .eq. 1) then
             avlbed(ireg,icat) = avlbed(ireg,icat) - load(ireg)
           endif
           crload(ireg)=crload(ireg)+load(ireg)
             delay = delayt
             do 650 i = 1,load(ireg)
               call rmove(1,catq,atrib)
               delay = delayt
               call enter(19,atrib)
               j(ireg) = int(hpstay)
               ibed(ireg,idest,icat,j(ireg)) =
     &                 ibed(ireg,idest,icat,j(ireg)) + 1
 650         continue
             if (crload(ireg) .eq. 40) then
               flytme = totdel
               return
             endif
 640      continue
 609      if (ih .eq. 1) then
            if (totdel .eq. 0) then
              goto 600
            else
              flytme = totdel
              return
            endif
          endif
 620      continue
 600      continue
          return
```

```
      elseif (gdis .gt. 900.0 .and. gdis .le. 1000.0) then
        speed = 379.0
      elseif (gdis .gt. 1000.0 .and. gdis .le. 1100.0) then
        speed = 384.0
      elseif (gdis .gt. 1100.0 .and. gdis .le. 1200.0) then
        speed = 389.0
      elseif (gdis .gt. 1200.0 .and. gdis .le. 1300.0) then
        speed = 393.0
      endif
      time = gdis / speed + 1.0
      delayt = delayt + time
*
      rdis = dis(ispoke,1,ides)
      if (rdis .le. 100.0) then
        speed = 240.0
      elseif (rdis .gt. 100.0 .and. rdis .le. 500.0) then
        speed = 327.0
      elseif (rdis .gt. 500.0 .and. rdis .le. 600.0) then
        speed = 343.0
      elseif (rdis .gt. 600.0 .and. rdis .le. 700.0) then
        speed = 355.0
      elseif (rdis .gt. 700.0 .and. rdis .le. 800.0) then
        speed = 365.0
      elseif (rdis .gt. 800.0 .and. rdis .le. 900.0) then
        speed = 372.0
      elseif (rdis .gt. 900.0 .and. rdis .le. 1000.0) then
        speed = 379.0
      elseif (rdis .gt. 1000.0 .and. rdis .le. 1100.0) then
        speed = 384.0
      elseif (rdis .gt. 1100.0 .and. rdis .le. 1200.0) then
        speed = 389.0
      elseif (rdis .gt. 1200.0 .and. rdis .le. 1300.0) then
        speed = 393.0
      endif
      iretrn = rdis / speed + 1
*
      totdel = delayt + iretrn
      if (totdel .gt. 16.0 .or. sortie .gt. 5)then
        flytme = totdel - iretrn - time
        return
      endif
      istart = idest
      istar = ides
      do 640 icat = 1,5
         if (ireg .eq. 1)then
           catq = icat
         elseif (ireg .eq. 2)then
           catq = icat + 5
         elseif (ireg .eq. 3)then
           catq = icat + 10
         endif
```

```
      if(ireg .eq. 3) then
        if (ispoke .eq. 8) then
          idest = ic + 1
          if (idest .gt. 8) then
            ih = 1
            goto 609
          endif
        elseif (ispoke .eq. 9) then
          idest = ic + 8
          if (idest .gt. 19) then
            ih = 1
            goto 609
          endif
        endif
      endif
*
        ix = 0
        ides = ic + 1
*
        do 630 icat = 1,5
         if (ireg .eq. 1)then
           catq = icat
         elseif (ireg .eq. 2)then
           catq = icat + 5
         elseif (ireg .eq. 3)then
           catq = icat + 10
         endif
         ibeds = ibed(ireg,idest,icat,1)-ibed(ireg,idest,icat,2)-
     &        ibed(ireg,idest,icat,3)-ibed(ireg,idest,icat,4)-
     &        ibed(ireg,idest,icat,5)-ibed(ireg,idest,icat,6)-
     &        ibed(ireg,idest,icat,7)-ibed(ireg,idest,icat,8)
         if(ibeds .eq. 0 .or. nnq(catq) .eq. 0) then
           ix = ix + 1
         endif
630     continue
      if (ix .eq. 5)then
        goto 620
      endif
      sortie = sortie + 1
      gdis = dis(ispoke,istar,ides)
*
      if (gdis .le. 100.0) then
        speed = 240.0
      elseif (gdis .gt. 100.0 .and. gdis .le. 500.0) then
        speed = 327.0
      elseif (gdis .gt. 500.0 .and. gdis .le. 600.0) then
        speed = 343.0
      elseif (gdis .gt. 600.0 .and. gdis .le. 700.0) then
        speed = 355.0
      elseif (gdis .gt. 700.0 .and. gdis .le. 800.0) then
        speed = 365.0
      elseif (gdis .gt. 800.0 .and. gdis .le. 900.0) then
        speed = 372.0
```

```
          do 620 ic = 1,sphosp(ispoke)
*
          if(ireg .eq. 1) then
            if (ispoke .eq. 1) then
              idest = ic + 1
              if (idest .gt. 8) then
                ih = 1
                goto 609
              endif
            elseif (ispoke .eq. 2) then
              idest = ic + 8
              if (idest .gt. 14) then
                ih = 1
                goto 609
              endif
            endif
          endif
*
          if(ireg .eq. 2) then
            if (ispoke .eq. 3) then
              idest = ic + 1
              if (idest .gt. 9) then
                ih = 1
                goto 609
              endif
            elseif (ispoke .eq. 4) then
              idest = ic + 9
              if (idest .gt. 17) then
                ih = 1
                goto 609
              endif
            elseif (ispoke .eq. 5) then
              idest = ic + 17
              if (idest .gt. 26) then
                ih = 1
                goto 609
              endif
            elseif (ispoke .eq. 6) then
              idest = ic + 26
              if (idest .gt. 33) then
                ih = 1
                goto 609
              endif
            elseif (ispoke .eq. 7) then
              idest = ic + 33
              if (idest .gt. 40) then
                ih = 1
                goto 609
              endif
            endif
          endif
```

```
************************************************************
* THIS ROUTINE DETERMINES THE SPOKE THAT THE C-9 AIRCRAFT IS*
* TO FLY.  THE PATIENTS ARE LOADED BY CATEGORY.  THE FLYTIME*
* FOR THE PATIENTS IS CALCULATED  USING C-9 BLOCK SPEED AND *
* GREAT CIRCLE DISTANCE FLOWN.  THE AIRCRAFT FLIGHT TIME IS *
* CALCULATED AS THE SUM OF THE LEGS FLOWN PLUS THE RETURN   *
* TIME TO THE HUB.  THE BEDS OF THE CATEGORIES ARE UPDATED  *
* AFTER THE PATIENTS ARE DOWNLOADED                         *
************************************************************
6       ireg = int(reg)
        start(1)  = 1
        start(2)  = 3
        start(3)  = 8
        stop(1)   = 2
        stop(2)   = 7
        stop(3)   = 9
        sphosp(1) = 8
        sphosp(2) = 7
        sphosp(3) = 9
        sphosp(4) = 9
        sphosp(5) = 10
        sphosp(6) = 8
        sphosp(7) = 8
        sphosp(8) = 8
        sphosp(9) = 12
*
        ibeds = 0
        delay = 0
        delayt = 0
        flytme = 0
        iretrn = 0
        load(ireg) =0
        capcty = 40
        bedavl(ireg) = 0
        j(ireg) = 0
        sortie = 0
*
        do 600 ispoke = start(ireg),stop(ireg)
*
        if (nnrsc((ireg+1)) .lt. 1.0) then
          return
        endif
*
        istart = 1
        istar = 1
        load(ireg)=0
        sortie = 0
        crload(ireg)=0
        totdel = 0
        flytme = 0
        delayt = 0
        ih = 0
*
```

```
         endif
        ffload(ireg)=ibed(ireg,l,icat,l) - ibed(ireg,l,icat,2)-
     &   ibed(ireg,l,icat,3)-ibed(ireg,l,icat,4)-ibed(ireg,l,icat,5)
     &  -ibed(ireg,l,icat,6)-ibed(ireg,l,icat,7)-ibed(ireg,l,icat,8)
         if (ffload(ireg) .ge. nnq(catq)) then
           ffload(ireg) = nnq(catq)
         endif
         if (ffload(ireg) .le. 0) then
           goto 90
         endif
         if (ireg .eq. 1) then
           avlbed(ireg,icat) = avlbed(ireg,icat) - ffload(ireg)
         endif
         rv = reg
         do 100 i=1,ffload(ireg)
           call rmove(1,catq,atrib)
           reg = rv
           call enter(19,atrib)
           j(ireg) = int(hpstay)
           ibed(ireg,l,icat,j(ireg))=ibed(ireg,l,icat,j(ireg))+l
100      continue
90     continue
       return
*************************************************************
* THIS ROUTINE ENTERS THE NUMBER OF AVAILABLE C-9S INTO THE *
* SLAM NETWORK IF THERE ARE PATIENTS IN THE QUEUES AND THERE*
* ARE SUFFICIENT BEDS AVAILABLE.                            *
*************************************************************
5      iql= nnq(1)+nnq(2)+nnq(3)+nnq(4)+nnq(5)
       iq2= nnq(6)+nnq(7)+nnq(8)+nnq(9)+nnq(10)
       iq3= nnq(11)+nnq(12)+nnq(13)+nnq(14)+nnq(15)
       ireg = int(reg)
       if (ireg .eq. 1 .and. iql .eq. 0) then
         return
       elseif (ireg .eq. 2 .and. iq2 .eq. 0) then
         return
       elseif (ireg .eq. 3 .and. iq3 .eq. 0) then
         return
       endif
       if (nnrsc((ireg+1)) .eq. 0) then
         return
       endif
*
       xc = reg
       do 95 i = 1,nnrsc((ireg+1))
         reg = xc
         call enter((15+ireg),atrib)
95     continue
       return
```

```
          ic4 = 0
        else
          ic4 = 1
        endif
      endif
      if (nnq(5) .gt. 0)then
        if ((avlbed(ireg,5) - nnq(5)) .ge. 0)then
          ic5 = 0
        else
          ic5 = 1
        endif
      endif
      if ((ic1+ic2+ic3+ic4+ic5).ge. 1)then
        flag = 1.0
      endif
    return
***************************************************************
*  THIS ROUTINE OFFLOADS THE PATIENTS FROM AIRCRAFT ARRIVING *
*  TO THE HUB HOSPITAL IF BEDS ARE AVAILABLE                 *
***************************************************************
4         if((nnq(1)+nnq(2)+nnq(6)+nnq(7)+nnq(11)+nnq(12)+nnq(3)+nnq(4)+
     &    nnq(5)+nnq(8)+nnq(9)+nnq(10)+nnq(13)+nnq(14)+nnq(15)).gt.5000)
     &    then
          mstop = (-1)
          endif
        i=0
        ireg = int(reg)
        if (ireg .eq. 1) then
          flag = 0
        endif
        j(ireg)=0
        capcty=40
        crload(ireg)=0
        ffload(ireg)=0
        load(ireg)=0
        iq1= nnq(1)+nnq(2)+nnq(3)+nnq(4)+nnq(5)
        iq2= nnq(6)+nnq(7)+nnq(8)+nnq(9)+nnq(10)
        iq3= nnq(11)+nnq(12)+nnq(13)+nnq(14)+nnq(15)
*
        if (ireg .eq. 1 .and. iq1 .eq. 0) then
          return
        elseif (ireg .eq. 2 .and. iq2 .eq. 0) then
          return
        elseif (ireg .eq. 3 .and. iq3 .eq. 0) then
          return
        endif
        do 90 icat=1,5
          if (ireg .eq. 1) then
            catq = icat
          elseif (ireg .eq. 2) then
            catq = icat + 5
          elseif (ireg .eq. 3) then
            catq = icat + 10
```

```
              avlbed(ireg,icat) = avlbed(ireg,icat) - load(ireg)
              rv = reg
              do 60 i = 1,load(ireg)
                call rmove(1,icat,atrib)
                reg = rv
                call enter((7+ireg),atrib)
60            continue
          itotld = itotld + load(ireg)
          load(ireg) = 0
50        continue
              if(itotld .gt. 0) then
                if (ireg .eq. 2) then
                  call enter(12,atrib)
                elseif (ireg .eq. 3) then
                  call enter(14,atrib)
                endif
              endif
63        continue
          return
************************************************************
* THIS ROUTINE CHECKS TO SEE IF SUFFICIENT BEDS ARE        *
* AVAILABLE FOR THE PATIENTS IN QUEUES. IF THERE ARE NOT   *
* SUFFICIENT BEDS THEN THE FLAG IS SET EQUAL TO ONE WHICH  *
* ALLOWS SLAM TO SCHEDULE AIRCRAFT FOR THE NEXT REGION     *
************************************************************
8         ic1 = 0
          ic2 = 0
          ic3 = 0
          ic4 = 0
          ic5 = 0
            if (nnq(1) .gt. 0)then
              if ((avlbed(ireg,1) - nnq(1)) .ge. 0)then
                ic1 = 0
              else
                ic1 = 1
              endif
            endif
            if (nnq(2) .gt. 0)then
              if ((avlbed(ireg,2) - nnq(2)) .ge. 0)then
                ic2 = 0
              else
                ic2 = 1
              endif
            endif
            if (nnq(3) .gt. 0)then
              if ((avlbed(ireg,3) - nnq(3)) .ge. 0)then
                ic3 = 0
              else
                ic3 = 1
              endif
            endif
            if (nnq(4) .gt. 0)then
              if ((avlbed(ireg,4) - nnq(4)) .ge. 0)then
```

```
*********************************************************************
* THIS ROUTINE FINDS THE NUMBER OF AVAILABLE BEDS IN EACH CATEGORY,*
*      AT EACH HOSPITAL, IN EACH REGION -- EVERY 24 HOUR PERIOD    *
*********************************************************************
2          do 30 ireg = 1,3
             do 30 ihosp = 1,40
               do 30 icat = 1,5
                 dischg=int(ibed(ireg,ihosp,icat,2)/(7-wkday+1))
                  avlbed(ireg,icat)=avlbed(ireg,icat) + dischg
                 ibed(ireg,ihosp,icat,2)=ibed(ireg,ihosp,icat,2)-dischg
30           continue
           if((nnq(1)+nnq(2)+nnq(6)+nnq(7)+nnq(11)+nnq(12)+nnq(3)+nnq(4)+
     &     nnq(5)+nnq(8)+nnq(9)+nnq(10)+nnq(13)+nnq(14)+nnq(15)).gt.5000)
     &     then
           mstop = (-1)
           endif
           return
***************************************************************
* THIS ROUTINE LOADS AND ROUTES THE CRAF FROM DOVER TO HUB    *
***************************************************************
3        ireg = int(reg)
         flag = 0
         if(ireg.eq. 3) then
         endif
         if(nnrsc(1) .eq. 0) then
           return
         endif
         crload(ireg) = 0
         capcty = 100
         itotld = 0
         load(ireg) = 0
*
         do 63 k = 1,nnrsc(1)
           itotld = 0
           load(ireg) = 0
*
           do 50 icat = 1,5
             if (nnq(icat) .gt. 0) then
               if (nnq(icat) .gt. avlbed(ireg,icat)) then
                if ((crload(ireg)+avlbed(ireg,icat)).gt.capcty)then
                   load(ireg) = capcty - crload(ireg)
                 else
                   load(ireg) = avlbed(ireg,icat)
                 endif
               else
                 if (nnq(icat) .gt. capcty) then
                   load(ireg) = capcty
                 else
                   load(ireg) = nnq(icat)
                 endif
               endif
             endif
             crload(ireg) = crload(ireg) + load(ireg)
```

END

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